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86th Congress
2d Session } JOINT COMMITTEE PRINT

BACKGROUND MATERIAL FOR THE REVIEW OF THE INTERNATIONAL ATOMIC POLICIES AND PROGRAMS OF THE UNITED STATES

REPORT

TO THE

JOINT COMMITTEE ON ATOMIC ENERGY

CONGRESS OF THE UNITED STATES

VOLUME 4

OCTOBER 1960

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BACKGROUND MATERIAL FOR THE REVIEW

OF THE

INTERNATIONAL ATOMIC POLICIES AND PROGRAMS OF THE UNITED STATES

By

ROBERT MCKINNEY

LETTER OF TRANSMITTAL

OCTOBER 1960.

Hon. CLINTON P. ANDERSON,
Chairman, Joint Committee on Atomic Energy, Congress of the United States, Washington, D.C.

DEAR MR. CHAIRMAN: On September 14, 1959, you requested that I undertake for the Joint Committee on Atomic Energy a review of the international policies and programs of the United States relating to the peaceful uses of atomic energy.

The review has been completed. I take pleasure in transmitting to you herewith my report, together with the background material assembled in the course of its preparation.

I am grateful for the cooperation so freely given by governments and officials in public and private life throughout the free world, whose cooperation was essential to the conduct of this review. The assistance of the many departments and agencies of the executive branch of the U.S. Government was invaluable, as were the contributions of many private citizens and industrial organizations in the United States. I am particularly grateful for the support of the Joint Committee, its staff, and the Library of Congress.

Without the administrative assistance made available by the Atomic Energy Commission, and all the other support received, the conduct of this review would have been impossible. I should add, however, that the judgments, conclusions, and recommendations contained in volume I of this report are those of the author, and are not necessarily those of the Joint Committee on Atomic Energy or of the executive branch of the Government.

Furthermore, although the material contained in the background volumes was considered by the author in the preparation of volume I, it should not be assumed that its publication is intended to imply that the statements or opinions contained therein are subscribed to in the review or that their correctness is underwritten.

I appreciate this opportunity to serve you and the Joint Committee.

Respectfully,

ROBERT MCKINNEY.

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FOREWORD

Purpose

The Joint Committee on Atomic Energy has requested that facts and judgments pertaining to the current status of the international policies and programs of the United States as they relate to the peaceful uses of atomic energy be brought together, appraised, and evaluated in relation to their original premises and purposes, and that those alternative courses of action which appear to be open to those responsible for the formulation and execution of atomic policies and programs for the future be explored.

Such a review is now timely. Searching reexamination has already begun in many quarters in many nations as to whether competitive civilian atomic power is in itself an achievable near-term objective, or whether the extensive technical capabilities devoted thereto might better be directed to other purposes. The various international instruments and institutions in the peaceful atomic field and the broad objectives underlying their creation have come into question.

Other developments which make a current reappraisal timely include:

(1) The growing body of experience with more precise estimates and actual costs of reactor construction and operation both at home and abroad;

(2) Significant changes in the supply and the demand both of fossil fuels and fissionable materials;

(3) Changed prospects for an effective international safeguards system;

(4) Changed prospects for disarmament and for cooperation with the Soviet Union;

(5) Public concern with radiation hazards arising from reactor operation and the disposal of radioactive wastes.

Current pessimism about the outlook for peaceful atomic applications, especially for civilian atomic power, may be as much a product of misunderstanding as was yesterday's overoptimism. Certainly, the inherent realities of what atomic energy can do for mankind are no less today than 6 years ago. Undue pessimism could do irreparable damage. It is important, therefore, that the nations of North America and Western Europe most advanced in atomic technology resurvey their positions and, if necessary, reset their courses.

Scope

The review embraces U.S. relationships with industrialized and less-developed countries, with allied countries, and with Communist-dominated countries.

In order to assemble the review in the most useful form, studies have been made of the current and prospective status of civilian atomic power, and of other peaceful atomic applications; of informed

energy-resource estimates and energy-demand forecasts; and of the evolution of the international policies and programs of the United States in the peaceful atomic field.

While the review and evaluation are concerned with all geographic areas and all atomic applications, U.S. relationships with other nations of North America and Western Europe advanced in atomic power have received the greatest attention in this presentation so that it could be organized within manageable proportions. No implication of relative priorities as to geographic regions or programs is to be construed. The importance of U.S. relationships with other areas of the free world, including the less developed countries, and with the Soviet Union is evident.

Method

Several mechanisms have been employed to insure objectivity and to uncover as many relevant details as possible, both of fact and policy consideration. Reports on the status and prospects for atomic science and technology have been reviewed, evaluated, and summarized by recognized experts, selected on the basis of competitive proposals and working under contract to the U.S. Congress. Energy resources estimates and demand forecasts have been reviewed, evaluated, and summarized by a competent authority under contract to the U.S. Atomic Energy Commission. These data have been prepared without intervention or dictation from those conducting the review or others.

More than 200 interviews have been conducted by the review staff in 14 European countries, including the Soviet Union and Poland. Through these interviews, judgments were obtained from individuals concerned with the direction of national atomic programs and laboratories, and from key officials of the principal international atomic organizations.

Requests were addressed to the Soviet Union, paralleling those addressed to other nations, and conversations were conducted in the U.S.S.R., in Western Europe, and in the United States with high Soviet officials in connection with the review and the Soviet Union's contribution thereto. The only written material provided in reply by the U.S.S.R., however, was the Russian text of a speech by V. S. Emelyanov, previously published in English in the proceedings of the 1958 United Nations Conference on the Peaceful Uses of Atomic Energy at Geneva.

Judgments were also obtained both at home and abroad from responsible government and industry officials outside the atomic field concerned with formulation of broad national and international economic, financial, and political policies, with scientific and industrial planning, and with related commercial activities. These outside judgments were obtained in order to place atomic energy in the perspective of overall national and international objectives, and to avoid confining the review to narrow atomic areas.

The assembled factual reports, evaluations and opinions have been considered and weighed in the light of discussions with senior officials of the U.S. Department of State, the U.S. Atomic Energy Commission and the Joint Committee on Atomic Energy, and with their opposite numbers in North American and European countries advanced in atomic technology.

All of the specially prepared reports, memorandums, and evaluation reports assembled and carefully considered in the course of the review are reproduced in volumes 2–5 of this report, entitled "Background Material." Data and judgments obtained on a private basis have not been summarized, except where specific permission was obtained. Other reports and data previously published and used in the course of the review are referenced in the background material volumes and are available to the public.

BACKGROUND MATERIAL FOR CHAPTER 2—THE GROWTH OF ATOMIC RESEARCH CAPABILITIES

EXTRACT FROM LETTER TO ROBERT McKINNEY, FROM PIERRE HUET, DIRECTOR, EUROPEAN NUCLEAR ENERGY AGENCY

I am sending you herewith a note by Dr. Lew Kowarski, Scientific Adviser to the O.E.E.C. European Nuclear Energy Agency, setting out some considerations on atomic energy cooperation in the Sixties.

* * * * * * *

15th February 1960

CONSIDERATIONS ON ATOMIC COOPERATION IN EUROPE DURING THE SIXTIES

by

L. Kowarski
Scientific Adviser to the
European Nuclear Energy Agency (O.E.E.C.)

Chapter I. Basic ideas: situation in early 1960.

II. Cooperation in depth and in width; complementarity.

III. Forms of cooperation

1. Information Committees
2. Assigning Committees
3. Participations in national activities
4. Joint Enterprises.

IV. Fields of cooperation: research

1. High-flux reactors
2. Electronic computation
3. Studies of transient behavior
4. "Fuel-and-component Banks"
   Postscript to 1, 2, 3, 4.
5. Magneto-hydrodynamics.

V. Fields of cooperation: development and applications.

6. "Nearly proven" types of power reactors
7. Fluid-fuel reactors
8. Ship propulsion
9. Technology of reactor components
10. Reactor for production of research materials
11. Irradiation of food
12. Medical research.

VI. Summary and conclusions.

Chap. I. - BASIC IDEAS: SITUATION IN EARLY 1960

An appraisal of the aims and chances of atomic cooperation in Europe during the next decade must take into account some noticeable changes which have recently occurred in the accepted ideas on the prospects of atomic power. Most of the present-day atomic activities, national or international, have their roots in these ideas as they stood in mid-Fifties. This basis is no longer valid, and reminders to that effect could be recently heard from high places and from renowned observers. If to-day we wish to re-state the ends and means of cooperation, it is useful to summarize the main relevant ideas as viewed "then":

(a) It was believed that the supply of "classical" energy would fall behind the growth of the demand, leading ultimately to the risk of a world-wide crippling of economic progress and, in the more immediate future, to an increasing dependence of European economy on non-European sources of fuel.

(b) It was expected that reactor types then in the course of early development in the U.S. and U.K. would very soon be able to produce power at a cost only slightly higher than that of classical power in many areas (including Europe), and that the cost of gaining experience in actual production of nuclear power would be correspondingly slight.

(c) It was considered that countries of a size substantially smaller than that of the U.S. would derive a considerable advantage from pooling their resources and producing their kilograms of fuel and kilowatts of power in jointly-owned plants.

(d) Power production was seen as the earliest and most obvious practical application of nuclear technology: it offered a (then anticipated) ready market, the possibility of building in big sizes (and so reducing the capital cost per unit of output), and all the advantages of an immobile location. Adaptation to more exotic uses (propulsion, chemical processing etc.) would follow. (The actual development of the PWR concept in the U.S. had, for reasons of military priority, taken a different course; but the Nautilus still could, after all, be seen as a testing station for a basically landworthy design, later embodied in Shippingport).

The present-day views on the same points can be stated as follows:

(A) The supply position of classical energy, and the economic picture in general, have changed so as to remove any impending or approaching prospect of an energy deficit, whether worldwide or European.

(B) By the time the first-generation nuclear power stations went into operation, their costs turned out to be rather higher than expected, and the costs of their classical competitors rather lower (both because of cheaper fuel and of improved efficiency). The net cost of large-scale experimentation thus became so high as to frighten away many would-be entrants into the nuclear power field.

(C) No ready benefit can be expected from building largest-size manufacturing plants and therefore no obvious incentive exists for pooling production resources of various European countries.

(D) Since nuclear technology cannot, as yet, beat more classical methods in the field of centralized power production, development efforts should concentrate on those uses and conditions where the specific advantages of nuclear methods count most. Applications involving very high temperatures, freedom from refuelling, very high power densities etc. should be given a greater priority. This re-orientation will put a premium on those aspects of nuclear methods in which they differ most from classical technology and not on those in which they "manage to do nearly as well".

A historical analogy may be of use here. At the close of the 19th century, the young electrical industry did not go after some of the markets (railroads, cooking, prime movers in factories) in which its ultimate success could even then be forecast with certainty. It concentrated instead on such "freak" uses as lighting, electro-metallurgy and subway traction, and from many years of these it emerged strong enough in experience to attack its "classical" competitors on their own ground.

Do these changes of outlook mean that, during the later fifties, there has been too much investment, public and private, in nuclear plant, training of personnel and setting-up of organizations? Yes, if we think only in terms of short-term economic returns. Certainly no, if we bear in mind the ultimate necessity of tapping nuclear stores of power, and the extent of development work which remains to be done.

The lengthening of the time-scale and the increased importance of research and development have an immediate bearing on atomic cooperation in Europe. First of all it strengthens the need for cooperation: knowledge can be shared, since - unlike the kilowatts

and kilograms - it is free from subjection to physical conservation laws. Because of these laws, it makes sense for two nations to build two exactly similar production plants. But an exact duplication of a research project is sheer waste if there is no secrecy.

From its earliest beginnings, the European Nuclear Energy Agency (O.E.E.C.) has insisted on this link between the needs for cooperation and for research and development; it has striven for coordination of national research and development efforts in specific fields and for promotion of joint enterprises (see Chap. III).

Compared to already existing forms of cooperation, new ventures may come to reflect a shift of emphasis in the choice of the subject-matter. Long-term objectives such as breeding, and unusual materials, conditions and applications will become more important. This orientation is reflected in Chaps. IV and V.

With the objectives of atomic activities so re-defined, and with the prospect of a more vigorous cooperation, European brainpower gets a better chance to show its worth (as it has in CERN, where the first successful pooling of European competences immediately put Europe in the first rank). This may lead to an increased importance of Europe to the scientific and technological advance of the Western world.

Chap. II. COOPERATION IN DEPTH AND IN WIDTH; COMPLEMENTARITY

In any given case, if cooperation is envisaged, two quantitative dimensions have to be considered: the width, that is how many - and which - countries should cooperate; the depth, that is what proportion of the effort a given country devotes to a given field of action should be put in the common pool.

For pure production activities, as we have seen, incentives to cooperation are least compelling. Economically valid techniques must be "proven", that is ready to be acquired or transmitted. Plants can be built by single countries, or under bilateral agreements; only in exceptional cases the economic unit is so big as to require the joint financial effort of a group of countries.

For ventures presenting both economic and development aspects, the desire to share the knowledge and the cost of its acquisition may push towards internationalization, but for economic convenience regional groupings between neighbouring countries may be preferred.

If the aim of the activity is acquisition of knowledge and strictly or nearly nothing else, there is no reason for refusing international cooperation if it is feasible, or for excluding any major potential contributor. This gain of width may be accompanied by a loss of depth: concrete pooling of resources becomes more difficult as the number of participants grows, and a tendency may appear to limit cooperation to an exchange of reports and designs (see chap. III). At the extreme limit, when all the countries are included, the information-exchange aspect becomes quite predominant.

Complete pooling of substantial material resources is still possible in an area wide enough to contain all major Western European countries, as the example of CERN has shown in the field of fundamental physical research. In the applied-science domain, the joint enterprises recently launched by ENEA (Halden and Dragon in reactor technology, Eurochemic for research and development on the processing of irradiated fuels) point in the same direction. If our forecast of shift of European atomic cooperation towards research and development is true (both because R. and D. will claim a greater proportion of the total outlay and because R. and D. is better suited for cooperation), we shall expect - or at least recommend - the extension of cooperation over the whole of Western Europe. Will it spread even further, so as to involve the U.S. and Canada?

Two recent developments (both of them already under way in mid-fifties) have brought American and European atomics closer together: one is the disappearance of secrecy (leading to a far more efficient exchange of information and to easier personal visits) and the other is the narrowing of the gap between levels of general prosperity. Far more than it was the case 10 or 5 years ago, Western Europe and North America form a single "homogeneous" area in which every participant is able to make a worthwhile contribution.

This levelling-up is still incomplete, and geographical remoteness is still real; cooperation between Europe and America cannot be expected to become always and fully as deep as it is practicable inside Europe. But opportunities and inducements for sharing knowledge have become so obvious, that on either side of the Atlantic the other side must be taken into account as a source and as a recipient. In other words, the programmes must become complementary as between Europe and America in those fields where a deeper cooperation cannot yet be expected to cover the whole Western world.

The idea of taking into account somebody else's programme when devising one's own may appear more natural when we think of a small country which admittedly has much to learn, than when we think of a very big and very advanced country. Yet in the U.S. itself, recent

plans announced by the A.E.C. Division of Reactor Development include explicit references to the British experience with natural-uranium gas-cooled reactors, and to the Canadian emphasis on the natural-uranium D_2O-moderated reactors.

To ensure deep cooperation and/or complementarity, organizational forms may easily be provided wherever needed. An interesting example is afforded by the European-American Nuclear Data Committee, recently (September 1959) launched under the aegis of ENEA. All full members and associate members (this latter category consists of U.S. and Canada) of O.E.E.C. take part on an equal footing in its work, which aims at a more efficient sharing of efforts and results (see below). Similar formulae may be used in other fields.

Chap. III. - FORMS OF COOPERATION.

The two main ingredients of any cooperation are communication (between separate working bodies) and pooling (into a single working body). They occur in different proportions in the various forms of cooperation which so far have been tried.

1. Information Committees.

In this form separateness remains at a maximum. Delegates from distinct national or private organizations meet at more or less regular intervals, report on their results, compare and discuss; documents may be exchanged between, and in view of, meetings. Improvement of the sum-total of separate efficiencies comes from the free flow of ideas, or from a new light brought on past performances, or from the realization that in view of the results obtained in one country a similar line of research should be re-oriented or pruned off in another.

These benefits can sometimes be enormous: in European atomics, one has only to think of the European Atomic Energy Society, for internal exchanges, or of the Geneva Atoms-for-Peace conferences for a world-wide confrontation. And yet it seems that these inducements usually are short-lived. Scientific activity in the Western world has, after all, its own centuries-old system of mutual information: journals, reports, visits and symposia; setting-up of intensified exchanges through specially organized committees may be useful after a period of disruption of ordinary communication (as in atomic research during and after the war), or as a first step in a transition to a fuller form of cooperation. Two ways of such a transition may be seen:

(a) In addition to the discussion of past activities the Committee may consider reports on the intentions and plans of its member organizations. This leads quite naturally to collective

recommendations which as likely as not will aim at avoiding duplications, at a rational use of each member's particular capacities, etc. The Committee thus acquires an assigning competence (see below).

(b) The Committee may set up standing sub-committees, working parties, etc. to act between plenary meetings. These activities already involve some pooling of expert knowledge. If a definite joint enterprise is in view as a possibility, a working party may begin to act as an international design group, and the transition towards sizeable financial commitments may be quite gradual. CERN laboratory in Geneva went through precisely these stages, starting as an experts' committee organized by Unesco in 1951, and a similar line of development was followed by Eurochemic, since the first meetings of its experts at O.E.E.C. in 1956.

Information committees and meetings are quite a common feature of international atomic cooperation, whether under the aegis of a regional organization such as ENEA or Euratom, or world-wide. As a means of promoting international efficiency they are far less effective than some deeper forms of cooperation (see below) and as a seemingly acceptable substitute for these deeper forms they may be positively dangerous. As a first stage, and as a means of clarifying the objectives they may be quite useful.

2. Assigning committees.

This new term refers to a type of international activity which has an honorable place in the history of atomic development. It was developed during the war between the U.S., U.K. and Canada and was brought to life again in 1956, on a restricted scale but with a good success, as the Tripartite Nuclear Cross-Sections Committee. The European-American Nuclear Data Committee, already mentioned, may provide an interesting test case of the efficiency of this formula between a greater number of participants.

In principle, a Committee of this type may make concrete recommendations which will be followed, by the participants concerned, under a voluntary discipline and at their own cost. Thus a country particularly well equipped to undertake a certain kind of measurement, may perform it in the common interest, even if the original request comes from only a small number of members.

Under this form, communication progresses towards a division of labor. Financial autonomy of the participants is still essentially intact, although some small contributions may be necessary towards the maintenance of a secretariat, and some material transfers take place when equipment, materials or personnel is lent by one participant to another. A generalization of these transfers may lead to the creation of a common stock (see Chap. IV, No. 4) or to the building

of a jointly-owned facility; the transition towards a Joint Enterprise is then completed (see No. 1, 3, 6, 9 etc).

Short of such a transition, the Assigning Committee remains an attractive and concrete enough form of cooperation. Its steering clear of financial commitments is tempting, but in practice it may be found that voluntary discipline is hard to keep as long as there is no common property to watch and no common material objective to fan up the collective enthusiasm.

3. Participations in national activities.

A substantial injection of foreign staff and money into a national project may lead to a blend of national and international features. There was a non-American contingent at Los Alamos in 1944-1945 and a multinational one at Montreal and Chalk River; CERN has its quota of scientists from non-member nations. The rôle of the host country or community remains clearly dominant and the foreign participation is organized on a bilateral or individual basis, or may be clearly recognized as an international venture.

In the latter case we may speak of an "International House". The recognition of this form is new; as an example we may quote the ENEA-Euratom participation in the NDA heavy-water study (1959).

Some fields of research and development lend themselves particularly well to this form of cooperation (see Chap. V, No.7). It may yet prove to be the most practical way to initiate a closer cooperation between America and Europe.

An International House in a national establishment, with an aim, direction and material equipment of its own, may acquire a personality so distinct that even the nationals of the host country working on its staff may feel that they are part of the international project rather than of the host establishment. We have then a genuine Joint Enterprise with all the advantages of pooling and common ownership. Such enterprises are undoubtedly easier to create than those of a purely international kind (see below), because the host establishment provides a convenient material starting point, initial buildings and administrative services etc. A truly international spirit is, however, more difficult to develop from these beginnings and the host nation has to exercise a delicate balance between its rôles as a provider and a participant.

4. Joint Enterprises.

Whether created around a national nucleus (see above), or built from scratch on an exterritorial ground, a Joint Enterprise has its own budget, an internationally recruited staff and an

international governing body. It solves the dilemma between communication and pooling in the most radical way and we believe it to be the most efficient way of using the sum-total of the resources which the participant countries are willing to devote to a given field chosen as suitable for cooperation. The increased efficiency arises from :

(a) The possibility for each participating country to send its best specialists in a branch of knowledge or experience in which this country particularly excels. Thus a top-class theoretical physicist may have a chance to work on the same project with a better electronic engineer than the best he would be able to find in his own country. The possibility of putting together in a day-to-day working contact the best specialists chosen from several countries offers a unique opportunity to form a best-quality team, and why should nations embark on a research project with anything less than that?

(b) Pooling of material resources and joint ownership is the only way in which the participating nations can endow a research project with powerful single items of equipment such as an accelerator, a high-flux reactor, a telescope, etc. Creation of unique research facilities feeds the enthusiasm necessary to maintain the will to cooperation, and possession of these facilities attracts later on the most creative researchers.

(c) Actual presence in one place of all leading executives enables quick decisions to be made.

The greatest objection to the choice of a Joint Enterprise as a form of cooperation in a given field is a financial one: less radical forms appear to cost less and it is tempting to think optimistically about their shortcomings.

Since the advantages of pooling may become fully obvious only when international consultations have become a habit in a given field, it may be practical to start the cooperation in the form of a Committee or an International House and to see whether it develops propitiously. The benefit of an initial enthusiastic momentum may be lost by this approach, but the examples of CERN and ENEA show that this loss is by no means final. An initial lack of full homogeneity between the participants, or too great a geographical separation (as between Europe and America) may also force a gradual approach.

CERN offers so far the only example, with several years' successful experience, of a Joint Enterprise without a national nucleus. Eurochemic, although located in the vicinity of the Mol centre, has

been set up as an international company, with its own directorate, not dependent on any existing research organization.

As examples of joint projects started from national beginnings, we have Halden, which is an international enterprise operating a nationally-built and owned reactor; Dragon, whose object is the construction of an international reactor within the framework of a national research centre; and Ispra where an existing national research centre has been internationalized.

Chap. IV. - FIELDS OF COOPERATION: RESEARCH.

The twelve possible fields of cooperation discussed in this and the next chapter form a list which is neither complete nor a selection of best bets. For some of them international recognition has advanced to the point where further action seems easy; for some others, recognized as urgent, no such beginnings exist and this inaction should be remedied. Every case sheds its own light on the general principles outlined above.

In each of the proposed fields cooperation can be initiated at practically no cost, and carried to an expenditure on a scale of 10 - 100 million dollars. Early stages of cooperation may lead the participants to a greater mutual confidence and to make them ready to shoulder sizeable financial burdens (see Chap. III); or on the contrary, they may show that there is no immediate need for a large-scale joint investment (as in the case of the European study group on fusion). For this reason we did not quote any cost figures.

Experience shows that cooperative research projects succeed best if they are (a) built around a sharply defined objective, preferably a very concrete one such as designing and building a jointly owned item of equipment; (b) ambitious - advanced design, powerful machine etc. Ambitious material projects can be so costly as to deter prospective participants; the temptation to meet this dilemma by promoting cooperation on a cheaply lofty plane should be resisted.

Research and development fields in which concrete cooperation between European countries (and, in some cases and to some extent, between Europe and America) is already in existence have not been included in the list; references to most of them are made in various parts of this paper.

1. High-Flux Reactors.

The salient features of the present situation are:

(a) The existence in Europe of several nearly completed reactors

of the MTR/ORR type, reaching well into the 10^{14} - 10^{15} range of thermal flux, and of several completed or nearly completed heavy-water reactors just achieving the 10^{14} limit. Thus Europe is very nearly able now, and soon will be definitely able, to undertake research and testing of the kind that is being carried out in the most powerful American reactors existing at present.

(b) No definite plans exist in Europe for a facility in the 10^{15} - 10^{16} range. Thus, when the first American reactors of that kind begin to operate (about 1963), Europe will revert to a non-complementary state of equipment.

(c) No effort is made in the whole of the Western world for creating an over-10^{16} facility; some thought however has been given to the scientific justification of such an effort and to a preliminary design.

These three facts, each in its order of magnitude, point to a possibility of cooperation in three stages:

I. An assigning committee grouping the European owners of high-flux reactors, with a possible American participation. This committee would not only regulate theinternational use of the available space for irradiations, loops etc. (we understand that such a regulation is being prepared for the Euratom region, and it would be desirable to extend the scheme so as to include British and Scandinavian facilities); it should also recommend and supervise a specialization of adjacent equipment. The new higher-flux reactors being built in America have been designed according to a pre-established plan of specialization (Oak Ridge for transplutonics, Brookhaven for epithermal beams, etc.). It is not yet too late to introduce in Europe a measure of diversity if not in the reactors themselves (beyond the obvious two classes - H or D in the core), at least in their adaptation to definite types of use (loops, beams, capsules, etc.). Heavy hydrodynamics would be stressed in one center, extensive hot lab facilities in another, and so on; the choice would be decided by the minor (but still significant) differences in design of the reactors themselves, by the availability of personnel apt to handle this or that class of problems, by the needs of the local national program etc.

If a link is created in this way between the high-flux specialists of several countries, the next stage will follow quite naturally:

II. The necessity of an over-10^{15} facility will be recognized (as it has been in America) and an initiative will be taken internationally rather than nationally (if only for money reasons). A design committee will be easy to set up and if and when a common design is agreed upon, it is difficult to imagine that money for a joint enterprisewill be impossible to find. A European decision to leave this whole field of research to America seems unlikely (the only serious alternative would be a purely national enterprise); on the other hand, a European over-10^{15} reactor could easily be given some distinctive features enabling it to hold its own place side by side with the four American reactors at present being built.

III. If the knowledge of the over-10^{15} technology is thus allowed to spread over Europe, the scientific interest of an over-10^{16} facility may come to be recognized on an all-western basis, and on this wider basis it may become possible to undertake an effort which at present appears too big for the United States alone.

2. Electronic Computation.

Reactor calculations are quickly becoming synonymous with the use of electronic computers, and the mathematics involved (partial differential equations, Monte Carlo etc.) are of a kind which calls for fast operation and vast storage. Advanced atomic laboratories in U.S. and in Europe possess or use computers of a capacity at least comparable to IBM-704; this sets a pace which every other active research center will be forced to follow.

International cooperation will be useful to those laboratories which have their own access to a big computer (sharing of programs, standardization and elaboration of computing methods) and essential to the other laboratories. For the use of the latter, a jointly owned or hired computer could easily be installed under international auspices.

Such a joint computation center would quite naturally become an originator of new ideas in reactor computation and thus perform a useful service for all its shareholders, including those who have computers of their own. And it would afford a natural transition to the next stage which to-day appears remote, but may well materialize by the mid-sixties: the stage of the "next generation of computers" (Lark, Stretch, Atlas etc.). What to-day is a definite prospect for Los Alamos (at the cost of over $ 10 m.), may become tomorrow a necessity which less affluent research centers will be able to acquire only on a cooperative basis.

3. Studies of Transient Behavior.

Such studies have been conducted in many countries by theoretical and computational methods and, in fact, add up to a sizeable fraction of the load imposed on big computers by reactor designers. In addition, many "excursion experiments" have been performed especially in America, where construction of special facilities for such experiments has been a standard practice for many years. The early Borax series, the Spert series, Treat and Kewb have set a pattern which Europeans will have to follow if they do not want to rely entirely on remote American facilities.

An excursion reactor has to be built for its own sake and hardly as a direct prototype of some power concept which could conceivably be developed in the interests of a national economy. Arguments for international cooperation are particularly potent in this case. Some facilities may however be of national origin if, for example, it is decided to perform excursions with a reactor originally built for another or a wider purpose (this happened to EBR-1). Out of this beginning, a network of new facilities could be developed at various centers under the supervision of an Assigning Committee. The very novelty of this field may, however, be seen as a good reason for a radically new departure, that is for a frankly international Joint Enterprise. It remains to be seen whether the new European facilities can be designed from the start as complementary to those existing in America; a catching-up stage may be found necessary.

4. "Fuel-and-component Banks".

The proposal of an internationally owned store, from which standard components and rare ingredients could be borrowed as from a circulating library in order to perform some subcritical or low-power experiments, has been discussed on a world-wide basis. There are two reasons for a more regional approach: the practical argument of "homogeneity" (see chap. II) and the existence of the European-American Nuclear Data Committee, whose terms of reference include quite definitely an international "circulation" of materials and material devices which might be temporarily required in order to perform a measurement in the common interest.

A "bank" of this kind could therefore be started within the present limits of EANDaC's competence. However EANDaC is mainly concerned with basic constants and pure substances, rather than with ad hoc mixtures and assemblies of the kind most likely to interest the potential customers of the "bank". This dilemma may lead towards an enlargement of EANDaC's sphere or towards an autonomous "bank" maintained in order to serve experimentation of a less universal kind. Conceived in this latter way the "bank"

is more likely to be of use to smaller nations and enterprises rather than to more advanced or better provided customers who, on the other hand, are the most likely suppliers. Experimentation of universal validity should therefore be encouraged.

Postscript to 1,2,3,4.

If the four projects listed above are taken in their common-hardware aspect - an over-10^{15} reactor, a big computer, one or several excursion reactors, a common store of materials and components - they begin to add up to something like a European Community of Facilities for Reactor Research. Whether concentrated in one location (the Community thus becoming a Centre), or geographically dispersed, these four aspects of cooperation could hardly be pursued independently from each other. Taken together they would serve the European contribution to original reactor research, just as Arco serves a substantial part of the American contribution.

We are stating here a crowning aim, rather than a basic premise of European cooperation in reactor research. In each of the four lines summarized above it is possible to initiate well-defined cooperative efforts on a modest scale, which may bear fruit even if a "European Arco" proves difficult to achieve.

5. Magneto-hydrodynamics.

The interest of this branch of applied physics has been recognized in many European countries in connection with controlled fusion. Some recent American work suggests however the possibility that magneto-hydrodynamics may become of interest to the technology of fission reactors. The possible use of very hot gases in current-generating machinery is worth exploring, and the close proximity of this subject to rocketry and other military applications should not prevent a civilian approach, any more than the existence of thermo-nuclear weapons excludes a civilian interest in controlled fusion. There is already a European study group (with American participation) on fusion, sponsored by CERN; a similar group on ionized hot gases could be set up at first as an Information Committee with a view towards other forms of cooperation as soon as the development of the subject warrants such an initiative.

Chap. V. - FIELDS OF COOPERATION: DEVELOPMENT AND APPLICATIONS.

The contrast between acquisition of pure knowledge and practical development creates a curious dilemma: "purer" subjects lend themselves better to international cooperation, but are more difficult to finance. Somewhere along the scale there is an optimum chance of finding support and money for a concrete international project, and it may yet be found that the best way of fostering international atomic cooperation as a whole is to look for such optimal subjects.

6. "Nearly proven" types of power reactors.

Reasonably proven types such as Shippingport, Calder Hall and Dresden are by now close enough to commercial and national interests and widely international ventures in these fields can hardly be justified. For more advanced versions of the same types the situation is of course different, as shown by the already existing OEEC projects (boiling D_2O reactor at Halden, high-temperature gas-cooled reactor at Winfrith.)[2]

The D_2O/natural-U concept appears as a borderline case. It has been developed beyond the stage of obvious material difficulties, and yet no large-scale specimen of this type has yet been, or is soon to be, completed. No good answer exists as yet to some essential questions: how to calculate lattices, how to keep D_2O leakage at a tolerable level, what is the most practical coolant.[5]

The number and variety of initiatives taken in various Western countries in connection with this concept (Canada, U.S., France, Sweden, U.K., Switzerland, Spain...) show that there is an ample field for a joint effort and perhaps in no other field the advantages of working on an all-Western scale (rather than by local agreements such as U.S./Canada or Euratom) are so obvious. Starting with an Information Committee, the Assigning stage could quickly be reached in which every participant would concentrate on one or several definite aspects of development, results to be shared by all. There would be hardly a need for a large-scale Joint Enterprise, although the usefulness of a jointly owned facility such as a large loop, critical assembly or excursion reactor might become apparent as the collaboration proceeds.

The situation is much the same for several other "nearly proven" concepts such as superheat, fast breeding, etc. International interest in these types is less in evidence than in the D_2O/natural-U

type, probably because the latter promises to fulfill a very obvious and understandable need - that of power production in familiar conditions. As mentioned in Chap. I, reactor types first designed for less familiar requirements may yet prove more effective as an early stage of practical nuclear technology; priorities for a substantial international effort should therefore be carefully weighed.

7. Fluid-fuel Reactors.

In the recent reappraisals of the U.S. reactor policy, fluid-fuel reactors were given a rather low priority because of their novel technological features (requiring a long period of tentative experimentation) and because other types were promising a quicker way towards competitive electric power.

These reasons, valid enough for a national program, may yet lead to a quite different conclusion in the context of an international cooperative effort. If such an effort is directed towards longer-range development, then the necessity of prolonged experimentation should hardly be seen as a deterrent. The main question is whether the concept is basically sound and promising; if so, the eventual elimination of initial snags may be taken for granted. The experience accumulated so far in Oak Ridge (and, to a lesser degree, at Los Alamos) certainly seems to point that way.

Competition from those types which can produce power conveniently, but cannot breed, is, again, less relevant in a longer-range view. As an important class of potential power-breeders, fluid-fuel reactors are definitely entitled to their share of international attention.

Few fields of atomic technologyoffer so definite an inducement for cooperation between Europe and America. In the United States, because of a low budgetary priority, the fluid-fuel development is not so fast as it could be; in Europe some promising projects have developed on an insufficient scale, or have been stopped altogether. An International House at Oak Ridge could be of immediate interest both to Europe, as a way to re-activate its own competence in this field, and to America as a source of new approaches to the familiar problems of the American projects.

Further stages of cooperation might involve:

(a) the implantation in Europe of self-contained studies on corrosion,,slurry dynamics etc., in close touch with American reactor experiments;

(b) European reactor experiments, complementary to those carried out in America;

(c) a large-scale European-American experiment.

Among the fluid-fuel concepts at present pursued in the U.S., the molten-salts reactor seems to offer the best-prepared field for cooperation. For Lapré and Lampré, potentially no less interesting, a cooperative push is at the same time more needed, and more difficult to initiate. Aqueous solution work in America could be usefully supplemented by an enlarged European work on aqueous slurries.

8. Ship Propulsion.

Reactor types suitable for power production on land should in principle be usable for ship propulsion, although in the latter case a greater emphasis would be laid on some specific qualities such as compactness or low servicing requirements. A propulsion reactor could either be adapted from a proven power-producing type, or developed anew. Historically the second method came first, and in the future it may regain preponderance; in such a development Europe could cooperate with America complementarily or jointly. At present the first method seems to attract the greater attention and Europe has to catch up before offering a profitable cooperation. Even here some measure of complementarity with American effort appears possible.

There seems to be little point in building an internationally owned tanker or liner which would function as such; on the contrary, if a land-based prototype and/or a sea-going experiment are considered as necessary initial stages, the advantages of building them as a joint enterprise are quite obvious. All sea-faring nations of Europe would be interested and could contribute their experience, almost irrespective of their proficiency in nuclear technology proper. The transition from an Information Committee towards an international design group and then towards a joint construction would be smooth and its pace would depend almost exclusively on financial possibilities.

From ships to aircraft and to rockets the transition is less logical than it may seem. Quite different reactor types may be required and, before the propulsion is tackled specifically, fluid-fuel reactors, high-temperature gas-cooled reactors etc. may have to be studied more deeply for their own sake. Military aspects of the subject may prevent the international approach. We mention these problems here in order to specify more clearly the field of maritime propulsion, and also as another reminder against the pitfall of thinking about nuclear technology too exclusively in terms of power stations.

9. Technology of reactor components.

The usual practice in reactor development tends to exaggerate the differences between homologous components in different projects;

a more flexible approach could lead to a type of component less exactly tailored to fit a given reactor and yet superior in performance and economy, because of a greater amount of thinking spent on the component itself.

Such functional and analytic studies could be initiated on many kinds of components; here are a few examples:

(a) Fuel elements - this mention need not be elaborated. As an example of possible lines of study we may suggest the development of a method to test the burn-up without destroying the element.

(b) Control rods - could not variable shapes (fans, etc.) be given some attention as against variable positions?

(c) More instantaneous measurement of temperature than that possible with the present thermocouples.

(d) Inpile instruments with better resistance to irradiation.

An assigning Committee could ensure the proper coordination and complementarity; a Joint Enterprise seems hardly necessary in this field. Component gadgeteering is a field potentially rich in patentable ideas and particular care should be taken to avoid conflicts between the necessary protection of the inventors and the spirit of international cooperation.

10. Reactor for production of research materials.

Some materials needed in research can be produced only in highly specialized and costly reactors (transplutonics and certain highly-concentrated isotopes, cf. No. 2 above); many others, on the contrary, can be drawn, as by-products, from practically any chain-reacting system. There is an intermediate class of isotopic products-tritium, cobalt 60, laboratory amounts of U233 etc. - for which the construction of a relatively modest but efficient producer would be definitely worthwhile.

A detailed proposal of this kind was presented at the 1959 Forum Conference. One or two such reactors could easily cater for the research needs of any number of countries, much as Rjukan supplied heavy water to the prewar world. The interest - if not for the whole Western world, at least for Europe - of a joint enterprise of this sort is obvious. The same reactor could also be made to produce some commercial by-products (electric power, isotopes for industrial use etc.), so that the enterprise would not be entirely given to research and development purposes; this would hardly affect its feasibility on an international plane and in fact could even facilitate its financing.

The same reactor could possibly be used for studies of chemical processing by inpile irradiation.

11. Irradiation of food

A preliminary study at present in progress at O.E.E.C. aims at presenting a picture both of the research work going on at present in European countries on the subject of food irradiation, and of the European needs for this technique of food preservation.

It seems that certain categories of applications have by now progressed up to the pilot plant stage. One possible cooperative development might consist in the provision, under a joint ownership, of a small number of mobile irradiation units, administered from a home base which could also act as a center for distribution of information and results. Such an initiative could easily be combined with another international project such as Eurochemic or No. 1 and 10 above.

12. Medical Research

In the United States, facilities available at some of the National Laboratories led to a considerable development of highly specialized biological and medical research work which cannot at present be duplicated or developed in Europe. We may mention the medical reactor of Brookhaven, and, at Los Alamos, the whole-body counting facilities and the use of fast-neutron bursts from Godiva. The relevance of our general recommendations - international operation of facilities needed to acquire internationally shared knowledge, programs complementary to those pursued in America rather than repeating them, importance of material installations as a means of focussing and injecting reality into the will to cooperate - can be seen in this field as well as in many others discussed previously.

Chap. VI. - SUMMARY AND CONCLUSIONS

1. Most of the recent atomic programmes in Europe, whether national or international, were originally derived from ideas on the prospects of atomic power which were current in the mid-fifties. Many of these ideas are no longer valid and the principles of co-operation are in need of a re-statement.

2. The proper sphere of cooperation will lie increasingly in research and development (production of knowledge) and relatively less in mining and manufacturing (production of kilograms and kilowatts). A greater stress should be laid on those applications and conditions in which nuclear technology differs most, and most favorably, from conventional power technology. Materials and reactor types suitable to meet unfamiliar requirements should be given greater attention.

3. This evolution of the objects of cooperation enhances the value of pooling in joint enterprises such as those recently put in operation by ENEA and those which, in a smaller number of countries, constitute one of the main objectives of Euratom. Sharing of tasks and information, on the pattern of the European-American Nuclear Data Committee (recently launched by ENEA) is of equal importance.

4. In general prosperity, and in numbers of available brain- and manpower trained in nuclear techniques, Europe is now far closer to American levels than it was five years ago.

5. With the disappearance of secrecy, research and development programs will become mutually complementary within an area defined by a free circulation of information, easy access to the relevant research centers and a sufficient homogeneity of education and technology to enable each participant to make a worthwhile contribution.

6. The countries of Western Europe and North America form at present such an area. Organizational forms ensuring atomic cooperation within the area will have to be evolved.

7. Cooperation means either communication (between several working bodies) or pooling (into a single working body). Forms of cooperation vary according to the relative importance given to either ingredient. Committees for exchange of information are suitable for very wide areas of cooperation or as first stages; committees for a common discussion and sharing of tasks are a step towards pooling. International participations in national activities may range from a modest contribution to a full-scale joint enterprise; this latter form, whether built around a national nucleus or independently, gives the best opportunity for cooperative pooling.

8. Twelve specific fields of R. and D. are listed as suitable for Western cooperation, in addition to those where cooperation has already been established. The list includes: high-flux reactors (rational use of those already or soon in existence and, if necessary, joint building of a more powerful one); fluid-fuel reactors (cooperation between Europe and America appears to be particularly needed here); building-up and circulation of a common stock of rare materials (possibly leading up to a joint building of an isotope-producing reactor); ship propulsion. This selection is not meant to express an urgent preference, nor the whole list to exhaust the whole variety of possible fields of cooperation.

STAFF NOTE.—The following notes were prepared by Mr. W. B. Lewis, Vice President for Research and Development, Atomic Energy of Canada, Limited.

VALID AND CONTINUING OBJECTIVES FOR NATIONALLY SUPPORTED ATOMIC ENERGY LABORATORIES

(Bases for financial allocations)

1. NUCLEAR POWER	2. OTHER
(a) The leap forward.	(a) Basic research.
(b) True low cost electric power.	(b) Applications of byproducts.
(c) Chosen alternative lines.	(c) A way of life.

NOTES AND ILLUSTRATIVE EXAMPLES

1(a). Nuclear energy is specially concentrated in certain natural elements such as uranium, thorium, deuterium, and in lesser amount or in perhaps less accessible form in hydrogen, lithium, beryllium, boron, lead and bismuth and a further list of other elements. Established designs of nuclear fission reactors, however, extract only a small fraction of the potentially available energy from relatively few isotopes, so that the yield is at the most only a few times the total fission energy of the relatively rare uranium 235 isotope. Even though this established yield may be economic, it is recognized that the development of systems of higher yield may be fruitful and to establish breeding of fissile material economically would be regarded as a technological leap forward in nuclear power. Controlled thermonuclear reactions and the release of neutrons by high energy nuclear particle reactions would be further examples of the leap forward to an even greater abundance of accessible energy.

1(b). The nuclear power systems pioneered by the U.K. and by Canada derive so much energy from natural uranium that the basic fuel cost is much less than from coal or oil. By technological development, reductions of capital costs of plants and of fabrication costs of fuels already promise electric power in large blocks on base load at costs competitive with coal or oil at any significant distance from the coal mine or oil well. Further technological improvements are in prospect and represent a continuing objective for both laboratory research and manufacturing development.

Auxiliary techniques such as fuel reprocessing and waste disposal are other valid objectives in this class.

1(c) Other reactor designs may be developed to compete economically with the established types, even though requiring much exploratory research and development of materials on the one hand or applicable only in more restricted fields on the other. Examples are furnished by the Dragon project, the Organic Cooled Reactors, and the Fused-salt reactor. Provided the basic limitations are not glossed over, these make reasonable claims on national support.

2(a) The whole atomic energy prospect has resulted from basic research. Other examples of nationally valuable applications resulting from basic research may be quoted such as radar that benefitted so much both from techniques developed for television and from special radiofrequency devices such as the cyclotron. Many problems of plagues, pests, etc. that beset mankind in the past have been mastered or subdued by the knowledge resulting from basic scientific research. Hence it does not require much vision on the part of governments to afford support to basic research, especially over such a wide range of science as is covered by the field of atomic energy as revealed to all nations in the two United Nations Geneva Conferences on the Peaceful Uses of Atomic Energy.

2(b) On a small scale many applications of byproducts have proved profitable. For example, radio-cobalt has been applied both to radiation therapy and to radiographic work. Radioisotopes as tracers, and activation analysis, especially for impurities at low levels, have made possible research and diagnostic techniques in a very wide range, for example from locating leaks in water mains, to determining the flow of sap in trees and the body fluids in human beings both in health and in disease.

Other byproducts have been instruments for control in industrial production and many other technical operations.

2(c) It is recognized that for a nation to earn and keep the respect of the major industrial countries, they must possess experts in the basic science underlying modern techniques. Even if it is not possible for a small country to carry on basic research in those fields that require major equipment such as high flux reactors and multimillion volt accelerators, experts can be trained in these fields.

Even though for many years to come an economic plutonium extraction plant can be operated in only two or three places in the world because of the small amount of plutonium that will exist, experts can be trained by undertaking process development with small-scale pilot plants in these fields. Such activities may be judged profitable even when they do not rank as basic research.

Already over 25% of those graduating from universities in North America do so in scientific and technical fields. It may well be that in another generation or less there will come about a more general understanding of the scientific basis for the modern wealth of the world and the world will truly be entering a scientific age. Knowledge of science will no longer be restricted to a very small minority and much more of the affairs of the world will be handled by those with a knowledge of how to observe faithfully and deduce rationally and a marked change may become evident even in common life. The new interests that develop from such scientific habits will divert attention from the harbouring of historic grievances and the cultivation of hate. More ignorance of traditional "history" and more recognition of man's poorly developed knowledge of his natural environment may be well worth cultivating from the national exchequers. These thoughts recall the title, "Science, the Endless Frontier," of the report to the President on a Program for Postwar Scientific Research by

Vannevar Bush, Director of the OSRD in 1945. A frontier and especially the endless frontier of science provides a goal for endeavour that displaces fortuitous drifting and the resulting conflicts between groups and nations.

Financial support for scientific activities is therefore justifiable not merely on the narrow grounds of seeking prestige but on the broad basis of seeking a satisfactory way of life for a highly populated world.

MAY 12, 1960.

STAFF NOTE.—This article, prepared for the Review by Dr. Norman Hilberry, Director, Argonne National Laboratory, expresses the philosophy which governs the organization and operation of the International School of Nuclear Science and Engineering at Argonne, an example of international collaboration at the working level.

SCIENTIFIC INTERCHANGE, A BASIS FOR INTERNATIONAL UNDERSTANDING

The human race has reached the point at which it must compose its differences by peaceful means or face extinction. Atomic weapons are no longer the sole possession of the very few. While high efficiency requires high technical skill, enough is known throughout the world as to the basic requirements for the production of a bomb so that any nation which can produce the necessary fissionable materials can make atomic weapons. They might be of low efficiency but, at the very poorest, they far surpass in destructive power the best of conventional weapons. Beyond this they carry the potentials for mankind's annihilation. It is imperative, therefore, that mankind start immediately on the long hard road of establishing that mutual understanding upon which a social order based upon a code of universal law may eventually be built.

The task is truly a formidable one. Differences in language, differences in religion, differences in fundamental philosophy and differences in tradition which are, in many cases, the product of untold centuries of ethnic development all militate against mutual understanding and trust. Let us never forget that to each person of the peoples of the earth his own ethnic background is as "sacred" and as "just" as any other person's and none can say him nay. Music, art and literature come close to providing means for common understanding, yet even here the basic differences still find their reflections. Only in the area of science and technology is there a completely universal foundation upon which all peoples may build. We all live within the same universe and on the same planet. Consequently, we all share a common physical and biological world. The fundamental laws of nature are the same for all peoples regardless of race, political ideology, religion or tradition. It is here then that the greatest hope of establishing an area of understanding lies. It is upon this foundation that we can build with confident hope of positive achievement. True, this area of scientific and technical understanding

represents but a fragment of the full scope of human experience and affects directly only a few persons, the scientists and engineers, amongst the total of the peoples involved. However, as society progresses in the direction of becoming evermore scientific and technological, these scientific and technical persons play an ever more responsible role in the conduct of their nation's affairs. Small as the group may be and however slight the influence which they may immediately exert, nevertheless this avenue appears to be the only one completely open where full understanding can be achieved.

This thesis was in mind when the International School of Nuclear Science and Engineering was established at Argonne National Laboratory, operated by the University of Chicago for the Atomic Energy Commission, in March of 1955. International exchange of scientists has gone on with significant success for as long as science itself has existed; atomic energy opened a new and challenging field for such interchange. The Atomic Energy Commission, therefore, chose this approach as one of its first steps in the implementation of our national program of assisting the nations of the free world in the development of the peaceful uses of atomic energy. Since its start, the School has had 514 students; 100 of these have come from the United States and from the territory of Puerto Rico - the other 414 have come from 45 nations abroad. These students have represented the best scientifically and technically trained manpower of the countries from which they have come. Since English has become an almost universal language of science, command of English was required of all applicants and as a result the group did have a common language. However, their language was common not alone in that English words and grammar were used, but, more deeply, in that the scientific concepts and laws which were the subject of study and discussion were universal in their character. Each student could meet the others on common ground regardless of the corner of the earth from which he had come. He knew that the physical principles and the mental techniques of dealing with them were the same in his

training and in that of his fellow students. Each fitted in to the same "frame of reference," that of science itself. Each knew that his scientific achievements would depend only upon the character and quality of his own work. Here is an area of undisturbable equality, an opportunity which is independent of all social variables and which provides a sound foundation for mutual understanding. This scientific understanding, in its turn, provides a basis for at least a partial understanding of, tolerance for, or perhaps even acceptance of differences in social, psychological and political traditions. The sharing of responsibility and effort by members of a group assigned a scientific or technical project has established friendships not only between the foreign students and the staff of the School and the Laboratory and the American students, but also amongst the foreign students themselves. These friendships are providing many new channels of communication between foreign countries. The School, by publishing its quarterly International Bulletin, is helping to keep these channels of communication open and alive.

To realize what these channels of communication mean, one needs to get out into the far corners of the world and see what is being done by the graduates of the School. In the less industrialized countries, many of these men are filling positions of major responsibility -- positions at a level where political policy is determined. Others, in the industrial nations, are filling positions high in the technical organizations of their nations. They are sharing in the responsibility for the determination of industrial policy. True, these policy decisions affect immediately only a narrow segment of the national interest. Nevertheless, for many of these nations it is an important segment and the fact that inter-nation discussions and understandings can take place between individuals who know and understand each other and who have a common reference point in their experience makes possible a new area of international cooperation. That the program has been vital and has been recognized in the countries of origin of the students is indicated by the fact that at the 1958 Geneva Conference eighteen papers were presented by

alumni of the School who attended the Conference as representatives of their home nations. At an alumni conference held at the Geneva meeting, ninety-five alumni attended, all of them having been sent to the meeting as representatives of their countries. Attached appendices present data concerning the graduates of the School and their country of origin as taken from our present records.

The first two sessions of the School were handled entirely by Argonne National Laboratory, since the facilities and curricula for work in this area had not yet been developed in American universities. Starting with the third session and continuing through the ninth and final session of the School, the basic half of the program was carried out at two universities which then had such curricula and the necessary facilities. These were North Carolina State College and Pennsylvania State University. The specialized half of the program was then carried out at Argonne. In the years that have intervened since 1955, the Laboratory has been engaged not only in carrying forward the School, but also in assisting American universities to establish curricula in this field. This it has done by the development of pedagogical tools for the field of nuclear engineering education and by the training of teachers through the conduct of summer institutes in the field.

Today numerous universities and other institutions, both in the United States and abroad, have acquired facilities and developed programs to provide basic nuclear engineering training. It has thus become desirable to modify the program of the International School to take advantage of this improved preparatory training and, consequently, to offer a broader range of opportunities than has heretofore been possible. In view of these changes in program, the School has now become the International Institute of Nuclear Science and Engineering. In conjunction with the staff of the Laboratory, the Institute now offers opportunities for advanced training and for research in the various fields of reactor science and technology, for research in selected areas of the physical and life sciences and for training in the administration and operation of nuclear facilities. The Institute, will, therefore,

make it possible for scientists and engineers from abroad to associate on an intimate working basis with the staff of the Laboratory and to utilize the best in research equipment that Argonne can provide. It is believed that the Institute now operating at the postgraduate, and, preferably, at the postdoctoral level will complement the opportunities which foreign and American universities now provide. It will continue to keep open the scientific pathway by which succeeding generations of scientists may in their turn continually expand the company of individuals whose ever increasing understanding of each others strengths and weaknesses, not alone in the field of scientific and technological endeavor, but also in the area of national aspirations and traditions, may eventually provide the world with that broad mutual trust essential for the rule of universal law and, hence, for peace.

Norman Hilberry, Director
Argonne National Laboratory
Argonne, Illinois
April 25, 1960

CHAPTER 3

ATOMIC POWER—INTERNATIONAL STATUS AND PROSPECTS

Section A

NOTE BY THE REVIEW STAFF

Two approaches were utilized in developing the raw data pertinent to this area of the review. The first was to request status reports from countries and international organizations with atomic power programs; the second was to engage the services of a competent organization for the purposes of summarizing, analyzing, and evaluating the responses and reports which were made available.

This section of background material begins with the report prepared under contract between Ebasco Services, Inc., of New York, and the Joint Committee on Atomic Energy. The various specific worldwide reports on the status and prospects for competitive atomic power are then presented.

The following invitation was sent to five firms qualified to perform the summary and evaluation services concerning the basic data for this chapter of the study. The night letter of invitation is reproduced below, in order to set forth the scope of the work actually undertaken by the selected contractor.

[Night letter]

DECEMBER 29, 1950.

Joint Congressional Committee on Atomic Energy invites you to propose on fixed-price letter-contract in connection with review of international policies and programs of the United States being conducted by Robert McKinney, described in forum memo, November, page 32. Copy of committee press release, descriptive speech and report outline forwarded to you today.

Contract work scope as follows: receive and determine adequacy of coverage of reports relating to peaceful central station power applications being prepared by other organizations for the review; evaluate, including by interviews or seminar with senior informed scientists, engineers, and industrialists to the extent required, the validity of the estimates of present status and forecasts of prospects for atomic power, fission, and fusion; and summarize the evaluation and set forth conclusions and independent appraisal. End work scope.

Status and prospect reports are scheduled for submission to the review group and the contractor by February 15. Summary and conclusions requested are to be available not later than April 15 in 25 copies. Letter or telegraphic proposal due by 3 p.m., January 7, delivered either c/o U.S. Atomic Energy Commission, room 1151, 1717 H Street NW., Washington, D.C.; or c/o U.S. Mission to United Nations, room 1927, 2 Park Avenue, New York City. State briefly where the work will be done, how work scope will be performed, the senior person responsible, estimated number of professional individuals, by profession, to be involved, and estimated number of man-hours of professional time required. Breakdown of cost to Joint Committee of interest, but not required.

Mr. McKinney's staff available to answer questions by telephone in New York on Murray Hill 3-6810, extension 291, on January 4 and 5, from 9 a.m. to 5 p.m.; and in Washington on Hazelwood 7-7831, extension 5761, on January 6, from 2 to 6 p.m.

Letter contract expected to be let directly by Joint Committee. Selected contractor will be notified on or about January 15.

JAMES RAMEY,
Executive Director, Joint Committee on Atomic Energy,
U.S. Congress.

EBASCO SERVICES
INCORPORATED
ENGINEERS - CONSTRUCTORS - BUSINESS CONSULTANTS
TWO RECTOR STREET
NEW YORK 6, N.Y.
CABLE ADDRESS EBASCO

W. H. COLQUHOUN
VICE PRESIDENT

May 9, 1960

Hon. Senator Clinton P. Anderson, Chairman
Joint Committee on Atomic Energy
Washington, D. C.

Dear Senator Anderson:

Submitted herewith is the report on the "Status and Prospects of Central Station Nuclear Power," prepared pursuant to the contract dated February 15, 1960 between the Joint Committee on Atomic Energy and Ebasco Services Incorporated.

Sincerely yours,

W H Colquhoun

INTRODUCTION

The objective of the study is to evaluate estimates of present status and forecasts of prospects for nuclear power in central station applications. This includes an appraisal of the validity of estimates prepared under the Atomic Energy Commission's Civilian Power Reactor Program, firm proposals by U. S. manufacturers for nuclear plants in the United States and in the Euratom countries, and projects actually under construction.

The scope of the review is limited to a consideration of nuclear plants of U. S. design and/or manufacture for installation at home and abroad, particularly in Western Europe, although some attention is given for comparative purposes to British and Western European nuclear plants for domestic installation and export.

Many factors enter into a determination of the cost of electricity from either nuclear or conventional central station power units in a particular situation. Factors appropriate to the specific circumstances must be applied in deciding which type of plant is most attractive economically. Hence, generalized estimates should be viewed with caution.

I - CONCLUSIONS

The following conclusions are drawn from the technical and economic facts and judgments evaluated during the course of this study.

A - GENERAL

1 - Technical Feasibility of Nuclear Power. Central station power units utilizing any one of several types of nuclear reactors are technically feasible and capable of being integrated into electric utility systems.

2 - Today's Nuclear Plants. Of all the nuclear plants which could be built today, in an established electric utility system, none appears under normal utility economics to be competitive with the most economically attractive conventional plant of comparable size that could be built at the same location. Today's nuclear plants may be construed as being competitive only if exceptionally favorable assumptions are made, such as high fossil fuel costs, low construction costs, a low rate of interest and other financial charges, and a high load factor.

3 - Tomorrow's Nuclear Plants. There is reason to believe that nuclear fission power will one day provide a substantial portion of central station electricity in many parts of the world. It is probable that the first really competitive nuclear plants can begin operation during the latter half of this decade in high-cost fuel areas of the United States and in some foreign countries.

4 - Factors Influencing the Growth of Nuclear Power. Significant reductions in the cost of nuclear energy can be derived from continuing research and from experience in the construction and operation of nuclear plants. However, the rate of growth of an economically competitive nuclear power industry will be determined largely by the availability and relative cost of alternate fuels.

B - REACTOR TYPES

1 - Light Water Reactors Today. Light water cooled and moderated reactors of the boiling water and pressurized water types are

the most promising in terms of lowest energy cost in mills per kilowatt-hour that can be built on the basis of current technology without extensive research and development cost, provided annual fixed charges on investment are comparable to those experienced by private utilities in the United States and provided a load factor approaching or exceeding 80 percent can be realized. The Atomic Energy Commission's Ten-Year Reactor Program is considered reasonable in its estimate that 300-megawatt electrical plants built on the basis of today's technology and operated in the United States under normal investor-owned utility practices with annual financial charges on plant investment of 14 percent will produce electrical energy at an 80 percent load factor for 9.6 mills per kilowatt-hour with either a boiling water or pressurized water reactor. The same energy cost would be obtained from a modern conventional thermal power plant of equal output burning coal, gas, or oil costing 63, 70, and 72 cents per million Btu, respectively. A pressurized water reactor plant of 150-megawatt electrical output producing energy at 11.8 mills per kilowatt-hour would be comparable to an energy cost of a conventional steam power plant burning coal, gas, or oil costing 78, 86, and 89 cents per million Btu, respectively. And a boiling water reactor plant of 150-megawatt electrical output producing energy at 12.0 mills per kilowatt-hour would be comparable to an energy cost of a conventional steam power plant burning coal, gas, or oil costing 80, 88, and 91 cents per million Btu, respectively.

2 - Organic Reactors Today. The AEC estimate for an organic-cooled and moderated reactor, based on currently proven technology, producing energy at 11.4 mills per kilowatt-hour in a 300-megawatt electrical plant is probably correct. The organic reactor is considered promising in the immediate future but because its technology is somewhat less developed than light water reactor technology, the building of the first organic power reactors will entail somewhat more economic risk than the light water reactors.

3 - Other Reactors Today. Other U. S. power reactors, on the basis of today's technology, would have significantly higher energy costs than the light water reactors.

4 - Light Water Reactors Tomorrow. Within the present decade, assuming that reasonable research and development effort is expended, it is reasonable to expect that the U. S. AEC's prediction can be realized that light water reactors can be developed and improved to produce electrical energy at a cost as low as 7.4 to 7.8 mills per kilowatt-hour in 300-megawatt electrical plants of the boiling water and pressurized water types, respectively. The same energy cost would be obtained from a modern conventional thermal power plant of equal output burning coal, gas, or oil costing 40 to 44 cents, 47 to 51 cents and 48 to 52 cents per million Btu, respectively. The successful development and application of nuclear superheat to either a pressurized water reactor or a boiling water reactor can reasonably be expected to reduce energy costs to about 6.7 mills per kilowatt-hour, which is comparable to coal, gas or oil, costing 32, 39, and 40 cents per million Btu, respectively. (All costs are in 1959 dollars.)

5 - Organic Reactors Tomorrow. It is believed the U. S. Atomic Energy Commission's expectation is correct that, should UO_2 fuel elements clad in a sintered aluminum alloy be demonstrated successfully, the potential organic reactor plant could go into operation by 1970 and produce energy costs as low as 6.7 mills per kilowatt-hour. The same energy cost would be obtained from a modern conventional thermal power plant of equal output burning coal, gas, or oil costing 32, 39 and 40 cents per million Btu. Research and development needed to prove the advanced type of fuel probably could be completed by the middle of 1963.

6 - Other Reactors Tomorrow. Provided that development problems are solved successfully, other currently less developed reactor types, i.e., sodium-cooled reactors and gas-cooled reactors, can be developed within 10 years with foreseeable advances in technology to produce electrical energy in large central station

power units at costs approaching those of water-cooled and organic-cooled reactors. As time goes on a continued improvement in all types of reactors can be expected. It is not possible, however, at this time, to estimate the ultimate potential in the sense of identifying which type of reactors are capable of producing lowest energy costs in the more distant future.

7 - Fusion Power. It is highly improbable that controlled fusion reactors can be developed rapidly enough and yield energy costs low enough to render fission power plants obsolete in the near future. The consensus of specialists in the industry seems to be that the first problem to overcome is an actual demonstration of a self-sustaining thermonuclear reaction followed by the development, design, and demonstration of a practical energy generating unit, before the potential of fusion power can be fully evaluated. Most estimates place this second stage of the problem at least 10 years in the future.

8 - Direct Conversion. Although the potential of the various "direct conversion" processes is difficult to assess, it does not seem probable that central station power applications can develop rapidly enough to render currently promising reactor plants obsolete in the near future. Furthermore, successful application of such processes or devices to nuclear fission reactors will require continuing development and operating experience from reactors much like those being developed today for use with steam turbines. In addition, it is quite possible that direct conversion schemes could also be applied effectively to generating electrical energy from fossil fuels.

C - CAPITAL COSTS

1 - AEC Estimates. The direct construction costs included in estimates presented by the AEC for its "current status" plants, i.e., nuclear plants which can be constructed immediately based on current technology, are realistic. Indirect costs applied in the AEC estimates are reasonably consistent with investor-owned utility practice in the United States.

2 - Firm Price Quotations. Firm price quotations for plants offered for construction in the United States to the date of this report are consistent with the AEC current status plant estimates.

3 - U. S.-Euratom Bids. Estimates for plants based on bids by U. S. manufacturers for construction abroad are consistent with the AEC estimates for "current status" plants. Available information on plants proposed under the U. S.-Euratom Agreement indicate that costs will lie within the range estimated by the U. S.-Euratom working group during negotiation of the Agreement and also within the range estimated by the "Three Wise Men," in 1957. The estimated energy costs for the ENSI project of SENN is 12.6 mills per kilowatt-hour at 80 percent load factor compared to the range 10.5 to 13.1 mills per kilowatt-hour given in "Target for Euratom" for a boiling water reactor and the range 11.7 to 13.9 mills per kilowatt-hour estimated by the U. S.-Euratom working group for either a boiling water reactor or a pressurized water reactor. The AEC 1959 estimate for a "current status" boiling water reactor plant is 12.3 mills per kilowatt-hour. The AKS group in West Germany considered a proposal for a 173-megawatt electrical plant based on an organic-cooled reactor. The energy cost for this project at 80 percent load factor has been estimated at 11.4 mills per kilowatt-hour based on a firm price bid compared to 12.8 mills per kilowatt-hour estimated by AEC for a "current status" organic-cooled reactor plant of equal output.

D - NUCLEAR FUEL COSTS

1 - Dependence of Enriched Reactors on AEC Prices and Policies. Nuclear fuel cycle costs for enriched reactors are strongly dependent on AEC prices and policies regarding materials and services. Even though, the current AEC charges are consistent with AEC stated policy of full cost recovery, AEC charges reflect both the advantage of government financing and the advantage of large-scale operation made possible by the military program. Substitution of commercial sources of materials and

services, assuming present technology, could increase fuel cycle costs significantly. To the extent that AEC policies, prices, and warranties remain in effect, the estimated fuel cycle costs are realistic.

2 - Effect of Reduction in AEC Charges for Enriched Uranium. A reduction in AEC charges for enriched uranium by 25 percent could result in savings of 0.4 to 0.7 mills per kilowatt-hour in the energy cost for a 150-megawatt plant of the water-cooled or organic-cooled reactor types, provided the credit for plutonium were unchanged. If the fuel value of plutonium is assumed to vary directly with the cost of enriched uranium, the net saving would be 0.3 to 0.6 mills per kilowatt-hour.

3 - Effect of Deferred Payment for Fuel Inventories. Deferred payment for fuel inventory purchases on terms permitted by the U. S.-Euratom Agreement gives utilities in Euratom countries the advantages of fuel inventory costs very nearly the same as those computed at the 4 percent lease rate available to users in the United States, provided only nominal surcharges are applied to the 4 percent interest rate charged for the deferred payment balance. On the other hand, utilities in countries not benefiting by the deferred payment provision would incur nuclear fuel cycle costs for a 150-megawatt plant which, for example, might be 0.6 to 1.1 mills per kilowatt-hour higher than those prevailing in the United States and Euratom countries if the financial charges on uranium purchases amount to 12 percent annually rather than 4 percent as assumed in the AEC studies.

4 - Effect of Warranties Under U. S.-Euratom Agreement. The combination of government and manufacture's warranties provided under the U. S.-Euratom Agreement for fuel element fabrication cost and minimum fuel exposure provide an upper limit to the effect of fuel element fabrication and processing costs on the resulting cost of energy for participating Euratom utilities. The same benefits are not currently available elsewhere. It must be recognized that insufficient experience has been accumulated to assure complete absence of fuel element failures

short of 10,000-megawatt-days per ton or other warranted level. The willingness of manufacturers to warrant such performance is an indication of their confidence that such warranties can be realized.

E - RESEARCH AND DEVELOPMENT REQUIREMENTS

1 - The research and development program outlined by the U. S. Atomic Energy Commission to realize the economic potential for each reactor concept is based on the maximum telescoping of effort as well as simultaneous parallel effort of several concepts. This program and the cost therefor are intended to represent the total effort needed to realize the potential improvement, whether the development is supported by AEC funds, industry programs or cooperating foreign laboratories. However, the dollar amounts do not include some industry-supported research currently underway nor the full excess cost of operating experimental and demonstration reactors included in the program over their expected operating life within the 10-year program. The estimates are conservative in that as work progresses the relative potential can be more clearly defined and the less promising de-emphasized.

2 - Attainment of the predicted potential by the state target dates is contingent on carrying out the research and development program on the schedule outlined. A deferral might extend the date for reaching the potential but not necessarily diminish the economic potential.

3 - Most of the possible reductions from presently obtainable nuclear energy cost will be evolutionary, requiring several generations of operating plants, with substantial operating experience on each generation. They cannot be achieved by research alone without operating experience but can be achieved with limited research and sufficient experience.

F - DEVELOPMENT PROGRAMS OF OTHER COUNTRIES

1 - United Kingdom. Natural uranium gas-cooled reactor development in the United Kingdom was predicated in some measure

on a public ownership system which requires only low financial charges and thereby minimizes the higher plant investment needed to take advantage of the relatively low cost for natural uranium. In addition, although the United Kingdom has facilities for enriching uranium, its costs are considerably higher than for the United States. The natural uranium gas-cooled reactor is less attractive, economically, where financial charges are those required for investor-owned utilities in Western Europe and the United States, particularly when supplies of enriched uranium from the United States are assured at a relatively low price. This is illustrated by the British gas-cooled plant to be built in Japan, for which estimates of power cost are 13.8 mills per kilowatt-hour initially and 11.3 mills per kilowatt-hour over the 20-year life of the plant.

2 - France. France has been active in developing natural uranium gas-cooled reactors and to a lesser extent heavy water natural uranium reactors. Emphasis on natural uranium reactors indicates a desire to push ahead on nuclear power development without dependence on external sources of enriched fuel material. In addition to use of natural uranium reactors for by-product plutonium, the French program includes active development aimed at plants for enrichment of uranium.

3 - Canada. Canadian reactor development for central station use is centered on heavy water moderated natural uranium reactors. Relatively low financial charges required in Canada counteract to some degree the higher investment cost of such reactors.

4 - U.S.S.R. Reports on the U.S.S.R. program indicate close parallels to the United States program in that a variety of reactor types are under development and that full-scale plants under construction are of the pressurized water and boiling water types.

II - NUCLEAR PLANT EXPERIENCE TO DATE

Actual experience in the construction and operation of nuclear power plants for central station application is extremely limited. However, limited as it is, the experience being gained in the construction of prototype and demonstration reactors is proving invaluable in the design of reliable and economical reactors for the future even though they themselves in no sense are competitive.

The generation of electricity for nuclear fission was first demonstrated by the Experimental Breeder Reactor on December 21, 1951. Subsequently, other reactor experiments have been constructed to demonstrate the feasibility of various reactor concepts of interest for central station plants. Many of these projects incorporated steam turbine generators but their value lay much more in providing data on reactor performance than in the token amount of electricity produced. A considerable amount of information, particularly for water-cooled reactors has been derived from prototypes and propulsion plants built and operated by and for the U. S. Navy and the Army power plant program.

The Shippingport Nuclear Power Station, completed in 1957, was the first nuclear plant designed for operation by a utility company for integration into a utility system. As of the first of 1960, the total nuclear electrical capability in the United States amounted to about 80,000 kw of which the Shippingport Station represented over 75 percent. This unit operated for 2 years on a highly experimental basis. The operation was successful, though not without trouble. Most of the difficulty experienced involved conventional components rather than the reactor and was of the sort that could and has been encountered in the start-up of conventional plants.

The Dresden Station reached critically in September 1959 and produced electric energy for the first time on April 18, 1960. At least 12 additional nuclear power plants are either under construction in the United States or have been committed for construction. In addition, two plants are being designed and fabricated in the United States for construction in Italy and the Japanese have indicated their intention to purchase

a small plant of U. S. design. The lessons learned in the operation of these plants over a period of years will provide the basis for significant reductions in the cost of nuclear energy and permit a much sounder appraisal of the economic prospects of nuclear power than is now possible.

In the United Kingdom, eight gas-cooled natural uranium power reactors are in operation at the dual-purpose plants at Calder Hall and Chapel Cross. While electricity generation is a by-product of plutonium production, the experience gained in construction and operation of these plants is being utilized in the design of the four nuclear power stations under construction and in additional plants in the planning stage in the British Isles and in the design of the plants to be exported to Japan and Italy.

Three gas-cooled power reactors are in operation at Marcoule, France and two larger units of similar type are under construction at Chinon.

A 5-megawatt nuclear power station using a light water-cooled, graphite moderated reactor has been operating at Obninsk in the U.S.S.R. since 1954. In September 1958, the Soviet delegation to the Second Geneva Conference on Peaceful Uses of Atomic Energy announced that a 100-megawatt nuclear power plant had been placed in operation at an unspecified location in Siberia. Three additional nuclear power plants are reported to be under construction in the U.S.S.R.

The Canadian program includes a 20-megawatt heavy water demonstration plant under construction and a 200-megawatt station using a heavy water reactor under design.

Tables 1 and 2 list nuclear power plants in operation and under construction throughout the world.

TABLE 1
NUCLEAR POWER STATIONS IN OPERATION

Designation	Owner	Location	Type	Net Electrical Power (KWE)	Criticality or Startup	Comments
(a) United States						
1) Shippingport Atomic Power Station	AEC & Duquesne Light Co	Shippingport, Pa	Press. Water	60,000	1957	1 Reactor 90,000 Kwe Turbo-Gen
2) Dresden Nuclear Power Station	Commonwealth Edison Co	Morris, Ill	Boiling Water	180,000	1959	1 Reactor
(b) United Kingdom						
1) Calder Hall A & B	UKAEA	Calder Hall	Gas Graphite	140,000	1956 (A) 1958 (B)	4 Reactors
2) Chapel Cross Nos. 1,2,3,&4	UKAEA	Chapel Cross	Gas Graphite	140,000	1959-1960	
(c) France						
1) G-1	CEA	Marcoule	Air Graphite)	50,000 Total	1956	1 Reactor
2) G-2	CEA	Marcoule	Gas Graphite)		1958	1 Reactor
3) G-3	CEA	Marcoule	Gas Graphite)		1959	1 Reactor
(d) USSR						
1) Obninsk	USSR	Obninsk	Graphite Moderated Light Water Cooled Pressurized	5,000	1954	
2) Siberia	USSR	-	-	100,000	1959	-

TABLE 2
NUCLEAR POWER STATIONS UNDER CONSTRUCTION
OR COMMITTED FOR CONSTRUCTION

Designation	Owner	Location	Type	Net Electrical Power (KWE)	Criticality or Startup	Comments
a) United States						
1) Consolidated Edison Thorium Reactor	Consolidated Edison Co.	Indian Point, N. Y.	Pressurized Water	255,000	1961	151,000 Kw Nuclear 104,000 Kw Superheat
2) Enrico Fermi Atomic Power Plant	Power Reactor Development Co.	Lagoona Beach, Michigan	Fast Breeder	94,000	1962	150,000 Kwe Turbo-generator
3) Yankee	Yankee Atomic Electric Co.	Rowe, Mass.	Pressurized Water	110,000	1960	
4) Elk River	AEC & Rural Cooperative Power Ass'n.	Elk River, Minn.	Boiling Water	22,000	1961	Includes 16,000 Kw Conventional Superheat
5) Hallam Nuclear Power Facility Sheldon Station	AEC & Cons. Pub. Pwr. Dist.	Hallam, Nebr.	Sodium Graphite	75,000	1962	
6) Piqua	AEC & City of Piqua, Ohio	Piqua, Ohio	Organic Moderated	11,400	1961	
7) Parr Shoals	Carolinas Va. Nuclear Power Assn.Inc.	Parr, S. C.	Pressure Tube Heavy Water	17,000	1962	1 Reactor
8) Consumers Power Co.	Consumers Power Co.	Big Rock Point, Michigan	Boiling Water	50,000	1962	
9) Humboldt Bay Power Plant	Pacific Gas & Electric Co.	Humboldt Bay, Calif.	Boiling Water	47,500	1962	Includes 104,000 Kw Conventional Superheat
10) ECNG-FWCNG	Florida West Coast Nuclear Group Inc	Florida	Gas Cooled, Heavy Water Moderated	50,000	1963	
11) Pathfinder Plant	Northern States Power Co.	Sioux Falls, S. D.	Boiling Water	62,000	1962	
b) United Kingdom						
1) Berkeley (Nos. 1 & 2)	CEGB	Berkeley	Gas Graphite	275,000	1961	2 Reactors
2) Bradwell (Nos. 1 & 2)	CEGB	Bradwell	Gas Graphite	300,000	1961	2 Reactors
3) Hinkley Point (Nos. 1 & 2)	CEGB	Hinkley Point	Gas Graphite	500,000	1962	2 Reactors
4) Hunterston (Nos. 1 & 2)	SSEB	Hunterston	Gas Graphite	320,000	1962	2 Reactors
5) AGR	UKAEA	Windscale	Gas Graphite	28,000	1961	
6) Trawsfynydd	CEGB	Trawsfynydd	Gas Graphite	500,000	1963	
7) Dungeness	CEGB	Dungeness	Gas Graphite	550,000	1963	
8) Greencastle	EBNI	Greencastle	Gas Graphite	180,000	-	
c) France						
1) EDF. 1	EDF	Chinon	Gas Graphite	53,000	1959	
2) EDF. 2	EDF	Chinon	Gas Graphite	170,000	1961	
d) USSR						
1) Beloyarsk	USSR	Beloyarsk	Boiling Water	100,000	1959	
2) Voronesh	USSR	Voronesh	Pressurized Water	420,000	1959	2 Reactors, 210,000 Kw Each
3) Volga	USSR	Uljanovsk District	Boiling Water	50,000		
4) Ural	USSR	Urals	Steam Formed in Reactor	400,000		

III - AEC AND UKAEA ESTIMATES OF ENERGY COSTS FROM NUCLEAR PLANTS

In June 1959, the Atomic Energy Commission undertook the task of reviewing its long-range program for civilian power reactor development. In the course of this study, the Commission examined on the basis of existing technology, the "current status" of various reactor concepts and the probable cost of electrical energy from their use in central station power plants built and operated under normal utility practices in the United States. In addition, the Commission made an evaluation of the economic "potential" of each reactor type and outlined a chronological development program aimed at achieving that potential.

It is not the purpose of the present study to repeat the very careful and comprehensive analysis made by the Commission, which is adequately presented in the four part report issued by the Commission under the title "Civilian Power Reactor Program." The Commission's report and much of its back-up material as well as additional material from other sources has been examined to judge the validity of its findings and to extend them to cover central station applications in other countries. The Commission's study, of necessity, was based on certain understandable limitations and carefully selected assumptions and these must be clearly recognized to place it in proper perspective.

A - AEC "CURRENT STATUS" PLANTS

In Part I of its study, reported in TID-8516 "Summary of Technical and Economic Status as of 1959" [(1)]*, the Commission compared the several available reactor concepts on the basis of plants which could be constructed immediately without dependence on additional research and development.

The more significant limitations and assumptions include the following:

1) The evaluation was limited to consideration of large central station nuclear power applications.

2) The evaluation was limited to the first unit of a station constructed on a site with normally favorable construction conditions and cooling water supply. It

* Numerical references listed in Bibliography

must be recognized that a multiple unit nuclear station using the same size units should be more economical to build and operate.

3) The power output rating of the nuclear units was limited to a maximum of about 300 megawatts. It may be expected that cost savings resulting from larger units would be greater for many nuclear concepts that would be the case for conventional thermal units. On the other hand, due to unfavorable economics based on current technology, it would be inadvisable to build plants for some concepts even as large as 300 megawatts.

4) Plant construction and operating costs were estimated on the basis of more or less detailed conceptual design studies. Finalized designs could lead to somewhat different costs and, in particular, modifications in concept which have not been explored as thoroughly might prove to be more economical than the concept chosen for a given reactor type.

5) Plant construction and operating cost estimates were subjected to a "normalization" procedure to assure uniform design philosophy, uniform costing of comparable equipment, uniformity and adequacy of service and auxiliary facilities, uniform construction periods and uniform application of indirect costs for all concepts. In the past, it has been difficult to assess cost estimates for different reactor concepts because of wide differences in design philosophy, estimating procedures and completeness of design supporting estimates of various groups and, even more important, because of inadequate identification of what cost items were or were not included in each estimate. The "normalization" procedures were essential to the AEC study. However, it must be recognized that the very process of trying to place the various

concepts on an impartial uniform basis may tend to mask some real cost differences between concepts.

6) In general, direct construction cost estimates were made for each reactor concept for plants of 75 mw, 200 mw and 300 mw based on flow diagrams and plant layouts. The cost estimates appear to be realistic. To the direct construction costs were added indirect costs, computed on a percentage basis, including engineering services, client administrative expenses and taxes, a 10 percent contingency, start-up costs equivalent to 4.5 months operation and maintenance expense and interest during construction based on a 36 month construction schedule (for a 300 mw nuclear plant). The indirect cost rates used are reasonably consistent with investor-owned utility experience and are considered appropriate for "normalized" estimates. It must be recognized that indirect costs vary considerably from one U. S. utility company to another and may vary even more for plants constructed abroad.

7) Plants were evaluated on the basis of 80 percent load factor and 14 percent annual fixed charge rate on plant investment. These assumptions are appropriate for the purposes of the AEC study, but values appropriate to the specific situation should be used in an actual application. This matter is discussed elsewhere in this report. In addition to the 14 percent annual fixed charge, which is assumed to include normal plant insurance, a separate item for nuclear insurance was estimated as an operating expense, including an all-risk nuclear property insurance computed at a cost of 35 cents per $100 of plant investment as well as the premium for nuclear liability insurance purchased from stock and mutual insurance pools at estimated rates and the charges for Government indemnity insurance established by the Price-Anderson Indemnity Act.

The estimate does not include the cost incurred for nuclear insurance required prior to plant operation by virtue of possession of special nuclear material.

8) All cost estimates are in terms of 1959 dollars, with no allowance for escalation for either "current status" plants or "potential" plants. While the omission was apparently deliberate because of the uncertainty of predicting inflation, prudent utility estimates include an allowance for rise in cost indices which have increased, on the average, between 3 percent and 4 percent annually for power plant construction since 1948.

9) Fuel cycle cost estimates are based on scheduled charges for AEC furnished materials and services currently in effect with one exception. The cost of fuel element processing was based on charges announced by the AEC in March 1957 whereas the charges in effect at the end of 1959 were approximately 8 percent higher due to adjustment for labor and materials cost indices.

10) Fuel cycle cost estimates were based on fuel irradiation levels specified for each type which are inferred from experimental data rather than from demonstrated performance. However, these levels are probably conservative in most cases.

11) Energy cost estimates are based on the equilibrium fuel cycle which in general is not established until two years to four years after plant start-up.

12) Construction cost estimates are exclusive of research and development costs. This is consistent with the assumption that "current status" plants should require no development. Furthermore, it has been general practice in the nuclear industry to segregate research and development costs to clearly identify actual manufacturing costs for comparative purposes. Manufacturers of power plant equipment normally recover research and development costs in their sales price and hence these become part of the utility plant investment

cost. Equipment prices used in the AEC estimates probably include some cost for developing new components but actual construction of a plant may involve some systems development which is not included. Furthermore, in view of the rapidly changing technology, any nuclear plant construction project in the near future probably will incorporate some new features. Accordingly, some associated research and development effort should be anticipated for each plant built whether its cost is charged to plant investment or not.

13) For comparative purposes, cost estimates were prepared for coal fired thermal plants of the same power range as the nuclear plants and using the same estimating procedures. These plants were designed for a fuel cost of 35 cents per million btu.

The results of the AEC "current status" study are presented in Tables 3 and 4. Table 3 presents data for 300 megawatt plants which were used by AEC for projections of economic potential. Table 4 presents comparable data for 150 megawatt plants, derived by interpolation. This is the nominal size selected for the United States-Euratom joint program. Each table also shows the equivalent cost of coal, oil and gas which, burned in a modern thermal plant of the same capability, would result in equal energy cost. Appropriate adjustments to the coal fired plant estimates prepared by Sargent and Lundy [3] for the AEC study were made to reflect the difference in plant optimization as a result of the variation in coal cost from the 35 cents per million btu value assumed for that study, and to reflect the consideration of oil and gas fuels. Discussion of the adjustment is presented in Section IV-E of this report.

On the basis of the assumptions used, both the pressurized water reactor and the boiling water reactor should produce electrical energy at 9.6 mills per kilowatt-hour in a 300 megawatt plant based on current status of technology. The equivalent cost of fuel in plants of the same capability burning coal, gas and oil which would result in the same total energy cost would be 63, 70 and 72 cents per million btu, respectively.

TABLE 3

ENERGY COST ESTIMATES

300 MWE "CURRENT STATUS" NUCLEAR PLANTS

Factor	Pressurized Water Reactor	Boiling Water Reactor	Organic Cooled Reactor	Sodium Graphite Reactor	Heavy Water Moderated Natural Uranium Reactor	Fast Breeder Reactor	Gas Cooled Reactor (Natural U Fuel)	Conventional Coal-Fired Plant @ 35¢/10^6 Btu
Fuel Exposure - MWD/MT	13,000	11,000	4,500	11,000	3,850	1½% Atom burn-up	3,000	-
Fuel Fabrication Cost - $/Kg	110	140	60	80	50	480/45	15.2	-
Capital Cost - $/Kw	244	263	220	303	360	255	380	168
Capital Cost - Mills/Kwh	4.90	5.26	4.39	6.11	7.05	5.10	7.60	3.32
Fuel Cost - Mills/Kwh	3.81	3.47	5.72	4.12	4.22	7.10	3.35	3.25
Operation and Maint. - Mills/Kwh	0.59	0.61	1.09*	0.70	0.93#	0.79	0.61	0.38
Nuclear Insurance - Mills/Kwh	0.26	0.27	0.25	0.29	0.30	0.26	0.33	-
Total Energy Cost - Mills/Kwh	9.56	9.61	11.45	11.22	12.50	13.25	11.89	6.95
1 - Cost of coal in cents/10^6 Btu for Equal Energy Cost	63	63	83	81	95	103	88	-
2 - Cost of gas in cents/10^6 Btu for Equal Energy Cost	70	70	89	87	100	108	94	-
3 - Cost of oil in cents/10^6 Btu for Equal Energy Cost	72	72	93	92	105	113	98	-

Notes:

All plants are based on the following:

(a) Load factor 80%.

(b) Fixed charges 14% annual on investment (excl. of fuel).

(c) AEC lease charge for enriched Uranium 4%.

(d) Credit for Plutonium produced $12/gram.

* Includes cost of organic coolant make-up.

Includes cost of heavy water make-up.

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TABLE 4

ENERGY COST ESTIMATES

150 MWE "CURRENT STATUS" NUCLEAR PLANTS

Factor	Pressurized Water Reactor	Boiling Water Reactor	Organic Cooled Reactor	Sodium Graphite Reactor	Heavy Water Moderated Natural Uranium Reactor	Fast Breeder Reactor	Gas Cooled Reactor (Natural U Fuel)	Boiling Water Reactor w/Superheat	Conventional Coal-Fired Plant @ 35¢/ 10^6 Btu
Operating Date	April 1966	June 1967	Jan 1967	Jan 1968	Jan 1969	Jan 1969	-		
Fuel Exposure - MWD/MT	13,000	11,000	4,500	11,000	3,960	1½% Atom burn-up	3,000	-	-
Fuel Fabrication Cost - $/Kg	110	140	60	80	50	480/45	15.2		-
Capital Cost - $/Kw	310	345	270	430	477	339	513		187
Capital Cost - Mills/Kwh	6.20	6.90	5.40	8.60	9.55	6.78	10.25		3.68
Fuel Cost - Mills/Kwh	4.12	3.80	6.05	4.70	4.49	7.59	3.58		3.40
Operation and Maint. - Mills/Kwh	1.00	0.84	1.48*	1.20	1.38#	1.17	.94		0.57
Nuclear Insurance - Mills/Kwh	0.43	0.43	0.40	0.50	0.58	0.46	0.48		-
Total Energy Cost - Mills/Kwh	11.75	11.97	13.33	15.00	16.00	16.00	15.25		7.65
1 - Cost of coal in cents/10^6 Btu for Equal Energy Cost	78	80	95	112	123	123	115		-
2 - Cost of gas in cents/10^6 Btu for Equal Energy Cost	86	88	102	119	129	129	121		-
3 - Cost of oil in cents/10^6 Btu for Equal Energy Cost	89	91	105	123	133	133	126		-

Notes:

All plants are based on the following:

(a) Load factor 80%.

(b) Fixed charges 14% annual on investment (excl. of fuel).

(c) AEC lease charge for enriched Uranium 4%.

(d) Credit for Plutonium produced $12/gram.

* Includes cost of organic coolant make-up.

Includes cost of heavy water make-up.

In the 150 megawatt size the total energy cost is estimated as 11.8 mills per kilowatt-hour from the pressurized water reactor and 12.0 mills per kilowatt-hour for the boiling water reactor. These are equivalent to fossil fuel costs in the range of 78 to 80 cents per million btu, for coal and correspondingly higher for oil and gas as shown in Table 4. Energy costs for other concepts using "current technology" are estimated at somewhat more than 1 mill per kilowatt-hour higher than for the light water concepts.

The organic cooled reactor deserves special mention because it is considered, along with light water-cooled reactors, as a "proven" type eligible for construction under the United States-Euratom Agreement for Cooperation. Although there has been much less experience in the development of organic cooled reactors than of water reactors, the organic cooled plant can be considered as technically feasible. Because of its simplicity the plant investment cost is attractively low. The principal uncertainty lies in the fuel cycle cost. The AEC "current status" estimate is based on fuel elements of uranium-3.5 percent molybdenum alloy, clad in aluminum, for which a burn-up of 4,500 megawatt days per ton is assumed. These assumptions represent the limit of current technology to about the same degree of conservatism as the corresponding assumptions for the water-cooled reactors but result in an energy cost of 11.4 mills per kilowatt-hour (for 300 mw plant) compared to 9.6 mills per kilowatt-hour for the water-cooled plants. The incentive for constructing a central station plant based on the current status of organic coolant technology lies in potentially low energy costs, provided that an improved type of fuel element can be developed, and on confidence that the anticipated performance of the new type of fuel element can be demonstrated in a relatively short time with modest development effort.

B - AEC "POTENTIAL" PLANTS

In Part II of its study titled "Economic Potential and Development Program," [2] the Commission considered improvements in technology which could be foreseen for the various reactor types within the next 10 years and estimated potential energy costs which might be obtained from full size reactors based on the improved technology. The same basic assumptions were used for these plants as were used for the "current status"

(d) Credit for Plutonium produced [illegible]

plants. The approach taken in projecting cost improvements for the advanced plants imposed the following additional restrictions:

1) The projections were made on the same reactor concepts covered in Part I and no major deviations in concept were considered, except that nuclear superheat was considered as a potential improvement for light water moderated reactors, and the aqueous homogeneous was added as being feasible by 1970.

2) The projected power costs take credit for only those cost reductions which can be identified readily. For each reactor concept, a target date was established by which a central station power plant can be built which should achieve the potential improvement. This does not mean that further cost reductions should not be expected beyond the target dates for virtually all reactor types.

3) No projection is made beyond 1970 for the reason that a development program aimed at solving specific, identifiable problems cannot be planned as much as 10 years in advance. At the same time, the potential costs estimated for the target dates do not necessarily represent the lowest nuclear power costs which may be achieved within the next 10 years, because cost reductions beyond those identified may be achieved.

4) The cost projection for each reactor concept assumes the successful completion of a specific development program on a schedule which contemplates a telescoping of effort to minimize development time. If unforeseen difficulties arise in the course of the development program or if some segments of the proposed development program are delayed or deferred the time at which the projected costs can be realized may be set back but the magnitude of the potential cost reductions need not be diminished.

5) Projections are made for 300 megawatt plants only, with no escalation from 1959 prices and the assumption is made that AEC charges and policies with respect to materials and service will be unchanged.

The AEC estimates of economic potential within these ground rules for the several reactor concepts are presented in Table 5. The table also shows the target date by which construction of a 300 megawatt electric plant could be completed which would achieve the "potential" economic performance after the equilibrium fuel cycle is attained. The light water-cooled reactors with nuclear superheat and the organic cooled reactors show the lowest energy cost although sodium and gas cooled reactors are also indicated to have a potential cost as defined, in the range of 7 to 8 mills per kilowatt-hour for 300 megawatt plants. The lowest figure of 6.7 mills per kilowatt-hour shown for the organic reactor and the boiling water reactor with nuclear superheat corresponds to a coal, gas and oil cost of about 32, 39 and 40 cents per million btu, respectively. The range of 7.4 to 8.0 mills per kilowatt-hour representative of other concepts is equivalent to coal costs in the range of 40 to 48 cents per million btu. For the most part, fuel cycle costs indicated for the "potential" plants after the equilibrium fuel cycle is reached could also be attained by the same time in plants of the same size built earlier than the target date.

In Part II of its report [2] the AEC outlines for each reactor concept a specific development program required to achieve the estimated potential power costs. These programs include the construction of appropriate test facilities, reactor experiments and prototypes deemed necessary for the particular concept. The development program for each concept is telescoped as much as possible and is assumed not to draw on development programs outlined for other concepts. Furthermore, the rate of accomplishing the outlined research and development is assumed independent of any budget considerations. For some concepts the technology is not sufficiently advanced to permit clear identification of key improvement areas. In such cases, the development program is oriented toward those areas believed to be most fruitful in identifying and establishing the potential improvement.

The estimated development costs are based on the total amount of effort needed to reach the specified potential cost for a given concept and

TABLE 5

ENERGY COST ESTIMATES
300 MWE "POTENTIAL" NUCLEAR PLANTS

Factor	Pressurized Water Reactor	Boiling Water Reactor	Organic Cooled Reactor	Sodium Graphite Reactor	Heavy Water Moderated Natural Uranium Reactor	Fast Breeder Reactor	Gas Cooled Reactor (Natural U Fuel)	Boiling Water Reactor w/Superheat	Conventional Coal-Fired Plant @ 35¢/10^6 Btu
Operating Date	April 1966	June 1967	Jan 1967	Jan 1968	Jan 1969	Jan 1969	-	-	
Fuel Exposure - MWD/MT	19,000	19,000	19,000	19,000	7,000	50,000	-	-	
Fuel Fabrication Cost - $/Kg	70	90	75	70	15	3,850	-	-	
Capital Cost - $/Kw	220	216	176	224	290	222	-	196	168
Capital Cost - Mills/Kwh	4.40	4.31	3.53	4.47	5.80	4.43	-	3.91	3.32
Fuel Cost - Mills/Kwh	2.56	2.29	1.83	2.00	1.21	1.99	-	1.96	3.25
Operation and Maint. - Mills/Kwh	0.59	0.61	1.09	0.70	0.91	0.79	-	0.61	0.38
Nuclear Insurance - Mills/Kwh	0.25	0.24	0.22	0.25	0.28	0.25	-	0.23	-
Total Energy Cost - Mills/Kwh	7.80	7.45	6.67	7.42	8.20	7.46	-	6.71	6.95
1 - Cost of coal in cents/10^6 Btu for Equal Energy Cost	44	40	32	40	48	40	-	32	-
2 - Cost of gas in cents/10^6 Btu for Equal Energy Cost	51	47	39	47	55	47	-	39	-
3 - Cost of oil in cents/10^6 Btu for Equal Energy Cost	52	48	40	48	57	49	-	40	-

Notes:

All plants are based on the following:

(a) Load factor 80%.

(b) Fixed charges 14% annual on investment (excl. of fuel).

(c) AEC lease charge for enriched Uranium 4%.

(d) Credit for Plutonium produced $12/gram.

are not intended to represent solely Government costs. Whatever effort is supplied by industry should be reflected in a reduction of Government expenditures. Similarly, power reactor research accomplished in other countries, if coordinated with the AEC program, would result in a corresponding reduction in United States effort. Neither foreign research nor United States industrial development would be expected to shorten materially the time needed to reach the estimated potential.

It is not possible, nor informative, to assess the validity of the overall dollar estimates for the required research and development program outlined by the AEC. However, certain implications of the ground rules used and other observations are worth noting.

1) The program cost figures for the several reactor concepts cannot be added to determine the total AEC program cost. As noted above, an implied duplication of effort exists on problems common to two or more concepts. Furthermore, the estimates were made for planning purposes only. The AEC must plan its budget and program on a year-to-year basis according to current objectives. It seems hardly necessary, for the purpose of achieving economic nuclear power, to develop some nine different concepts in parallel with the maximum telescoping of effort on the development of every concept.

2) In general, the specified potential cost reductions are reasonable, assuming the solution of development problems. The development programs appear to be based on a sound and comprehensive analysis of current status and on an identification of key areas for improvement.

3) No effort was made by AEC to identify the development costs of industry in any project not now under contract with the Government. In this respect the estimates do not represent the total development cost.

4) In the case of construction costs for prototypes and full scale plants, a differentiation was made between the total or gross cost and a net cost to the program computed as the differential construction cost in excess of that for conventional (coal-fired) plants of the same size. Excess operating costs are not indicated for full scale plants, except in the case of the Shippingport station. In this case, the cost, amounting to $125 million over the 10-year period, is excluded from the program cost summary. In the case of prototypes and demonstration plants, operating costs are shown for a five-year period only. Some reactor experiments may have outlived their usefulness after five years of operation. However, because much of the value of a prototype or demonstration plant lies in its usefulness for testing fuel elements, an assumption that such plants will continue to operate is probably justified. It is difficult to predict excess operating costs, but they should be recognized as part of the total program cost.

C - PLANTS IN THE UNITED KINGDOM

The United Kingdom Atomic Energy Authority furnished [4] the estimate of a typical British nuclear station of recent design shown in Table 6. The same source indicated that the first two commercial stations (Berkeley and Bradwell) cost about $420 per kilowatt output (exclusive of the initial fuel charge) whereas stations of the latest design cost between $336 and $364 per kilowatt. These stations are based on graphite moderated natural uranium reactors cooled with carbon dioxide.

Table 6

Costs for a Typical British Nuclear Station of Recent Design

Assumptions:

Capital Cost	£125/kW
Heat rating	3.1 MW(H)/T.U.
Thermal efficiency	28.8 percent
Initial cost of fuel	£20,000/T.U.
Credit for irradiated fuel	£5,000/T.U.
Irradiation	3,000 MWD/T
Rate of interest	5-1/2 percent
Life of plant	20 years
Total financial charge rate	8.36 percent

	Generating costs at 75 percent load factor	
	pence per kWh	mills per kWh
Capital charges	0.38	4.6
Fuel inventory	0.07	0.8
Fuel replacement	0.17	2.1
Operating costs	0.05	0.6
Total generating costs	0.67	8.1

Future reductions in plant investment and energy costs are expected from an Advanced Graphite Reactor (AGR) design now under development which will use slightly enriched UO_2 fuel elements clad in beryllium or stainless steel to obtain a substantial increase in fuel irradiation level (greater than 6,000 MWD per ton compared to about 3,000 MWD/ton for the present design) and higher gas temperature (525°C to 575°C compared to 400°C with present magnox cladding) an experimental reactor of this type rated at 28 MWE is under construction at Windscale for operation in 1961.

Estimates for an AGR type reactor presented by Sir William Cook (5) at the 1959 Stresa conference of the European Nuclear Energy Agency are as follows:

Reactor type AGR
Reactor output unspecified
Capital Cost $ 280 per kilowatt
Fuel enrichment 1%
Annual load factor 75%
Fuel irradiation 6,000 MWD per ton
Capital charges (13%) 5.8 mills per kwh
Interest on initial fuel charge (5%) 0.4 mills per kwh
Fuel replacement (net) 2.3 mills per kwh
Operating costs 0.6 mills per kwh
Total energy cost 9.1 mills per kwh

Using the capital charge rate of 8.36% appropoiate to operation in the UK the capital charges for this plant would amount to 3.6 mills per kwh and the total energy cost would be 6.9 mills per kwh.

IV - PLANT INVESTMENT ESTIMATES

Cost estimates prepared on the basis of conceptual or preliminary design studies depend on the judgment and experience of the estimators. Estimates based on a wealth of experience in the design and construction of a particular type of facility tend to be accurate. Nuclear plants involve much new technology and many uncertainties. Nevertheless, estimates of nuclear plants can be reliable if equipment requirements are accurately specified and the uncertainties identified. Estimates being prepared today, as typified by the AEC report, are much more sophisticated than those prepared a few years ago. Nevertheless, their reliability can only be verified by actual experience.

The best test of the reliability of a cost estimate is actual construction experience. Unfortunately, no central station nuclear plants have been completed for which costs are representative of normal commercial practices. Of more usefulness are estimates for plants under construction or for which firm purchase commitments have been made. Firm bids offered on a commercial basis by reactor suppliers also should be reliable, provided full cognizance is taken of cost items not covered in the supplier's bid. In some respects, because the state of the art is advancing so rapidly that a finished plant is obsolescent by the time it is placed on the line, estimates made from an analysis of bids may be more representative than estimates made for a plant already under construction. It should be noted, however, that a nuclear plant differs from a fossil fired plant in that advances in fuel technology can be applied to a completed plant so that obsolescence from the viewpoint of operating costs would be less rapid. Unfortunately, for business reasons, full cost details are rarely made public during the proposal or bid evaluation stages.

A - NUCLEAR PLANTS IN OPERATION OR UNDER CONSTRUCTION IN THE UNITED STATES

Construction cost estimates for plants in operation and under construction in the United States are shown in Table 7. The only full scale central station nuclear plant with any operating experience is the Shippingport plant, operated by Duquesne Power Company for the AEC, which went into operation in 1957. The costs for this installation are hardly representative of those expected for a plant to be constructed in the next few years. The plant is

TABLE 7

PLANT INVESTMENT FOR NUCLEAR POWER PROJECTS

Station	Reactor Type	Plant Capacity Net MWE	Estimated Cost		Start Up Date
			Million $	$/Kw	
Shippingport	PWR	92	72.5	790	1957
Dresdent	BWR	180	61.8	344	1959
Rowe (Yankee)	PWR	110	55.1	501	1960
Fermi (PRDC)	Fast	94	59.0	628	1960
Indian Point	PWR	255	107.5	422	1961
Elk River	BWR	20	12.8	640	1961
Piqua	OCR	10.5	11.3	1,080	1961
Hallam	SGR	75	52.0	693	1961
Saxton	PWR	5	8.4	1,680	1961
Pathfinder	BWR	62	23.6	381	1962
Parr	HWR	17	22.1	1,300	1962
ECNG-FWCNG	GC-HWR	50	25.3	507	1963
Peach Bottom	HTGCR	40	27	675	1963

Reference: AEC Annual Financial Report - 1959

highly experimental in nature and conservative because it is a first generation plant. Because the plant was built for the account of AEC some indirect cost items normally encountered in a utility plant were not incurred. Although the first core operated at a net power level of 60 mwe the equipment was sized for a net power of 92 mwe and the dollar per kilowatt cost is computed on that basis.

The Dresden plant of Commonwealth Edison Company is now operating at partial power tests. The plant was purchased at a contract price of $45.0 million, but this price is acknowledged to be below actual cost. The tabulated cost includes additional costs for land and indirect cost items, but no breakdown is available.

None of the plants listed in the table is expected to be economically competitive with conventional plants if normal financial charges are computed from the indicated investment cost. However, some of them may achieve economic operating and fuel costs during the useful life of the plant.

No costs are presented here for reactor experiments such as the Sodium Reactor Experiment, the Borax experiments or the experimental boiling water reactors at Argonne and Vallecitos even though these reactors as well as EBR-I and HRE-I have all produced electrical energy.

B - NUCLEAR PLANTS IN THE UNITED KINGDOM

The only power producing reactors operating in the U. K. are in the dual purpose plants at Calder Hall and Chapel Cross (four reactors at each location). They are primarily plutonium producers with by-product power. The construction cost of these stations has little bearing on the construction cost of a central station nuclear plant with electrical energy as the principal product. However, the technology utilized at Calder Hall and Chapel Cross and the experience gained in their operation have formed the basis for commercial nuclear plants now under construction in the U. K. and offered for export. Power stations in the U. K. are operated by regional electricity generating boards. A series of nuclear power stations of the gas cooled type is under construction and additional units are being planned. Stations are constructed by consortia of engineering, manufacturing and construction firms selected on the basis of firm price competitive bidding. The electricity boards have not released estimates of construction or energy generating costs for the commercial stations.

Typical published estimates for commercial U. K. stations are shown in Table 8. The investment costs given by Duckworth seem to be representative. It may be inferred that $406 per kilowatt is the approximate construction cost for the Berkeley, Bradwell and Hunterston stations and $336 per kilowatt is the approximate construction cost of the Hinkley Point and Trawsfynydd stations. A 1957 study sponsored by the AEC,[7] compared reactors of the Calder Hall and PWR (Shippingport) types for construction in the U. K., the U. S. and Japan. This study concluded that construction costs for power plants based on either of these reactor types would be approximately 50 per cent higher in the U. S. or Japan than in the U. K.

TABLE 8

ESTIMATED CONSTRUCTION COST OF U.K. GAS-COOLED REACTOR PLANTS

	Source of Information	Plant or Date	Capacity	$/kw	Basis
1.	1955 Geneva Conf P/390 (J A Jukes)		150	350	
2.	1958 Geneva Conf P/74 (R N Millar)	Hunterston	2x150	350	Contract price
3.	"Nuclear Engineering" March 1960		150	429	Incl int during constr
			2x250	302	Incl int during constr
4.	1959 Stresa Conf (Sir William Cook)		Not Spec	350	
5.	1958 Geneva Conf P/72 (J A Jukes)	Berkeley, Bradwell Hinkley Pt, Hunterston		322-406	Incl 5-10% for site developed.
6.	1958 Geneva Conf P/1446 (J C Duckworth et al)	1961	2x150	406	Include site development
		1962/1963	2x250	336	
		1963/1964	2x300	308	
		1965/1966	2x350	294	
		1967/1970	2x400	280	
7.	"Estimates of Nuclear Energy Production in Europe 1960-1965" OEEC (ENEA) (1959)	1961		400	assumptions
		1965		300	
8.	The Electricity Supply Industry In Europe Electricity Committee - OEEC (February 1960)	Berkeley, Bradwell and Hinkley Pt		406	
		Hunterston and Trawsfynydd		336	
9.	1960 UKAEA Statement	-		350	

C - NUCLEAR PLANTS FOR CONSTRUCTION ABROAD

Both U.S. manufacturers and the British consortia have submitted bids for construction of nuclear power stations abroad. Estimates are available which give an insight into the relation between the manufacturer's price and the cost of the finished plant.

1 - Project ENSI

The Italian nuclear power syndicate, Societa Elletronucleare Nazionale (SENN), invited proposals in October, 1957 for a 150 mwe nuclear plant to be constructed in Southern Italy, with the cooperation of the World Bank. The plant type was left to the discretion of the bidder. Nine proposals were received from four U.S. manufacturers, three British consortia, one French firm and a joint U.S. - U.K. team. Reactor types included two pressurized water reactors, two boiling water reactors, an organic moderated reactor and four gas cooled reactors. The bids were subjected to a comprehensive evaluation by the USAEC, the UKAEA, a U.S. consulting firm, a British consulting firm, a panel of International experts appointed by the Bank, and the SENN organization, which made the final selection. The choice made on a combined evaluation of economics, soundness of design and development potential was a General Electric dual-cycle boiling water plant. The project subsequently was approved for inclusion in the joint U.S. - Euratom program.

Various estimates of the capital cost of the plant have appeared from time to time. To avoid confusion, only the recent estimates used by the U.S. - Euratom Joint Review Board are analyzed here. It should be noted that the direct cost for construction and engineering, including civil structures furnished by SENN as well as equipment and services supplied under the IGE contract, are essentially those set forth in the original proposal. In Table 9 the cost breakdown is compared with corresponding items for a boiling water reactor plant of the same type and size derived by interpolation from Report SL-1674 - "Power Cost Normalization Studies - Civilian Power Reactor Program - 1959"[8] which formed the basis for the AEC "current status" plant. Items which are significantly different are the allowance for taxes, administrative expense, interest during construction and allowance for escalation. Interest on the SENN plant is

TABLE 9

ESTIMATES OF INVESTMENT COSTS
FOR
150 MWE BOILING WATER REACTOR PLANTS

Date of Estimate	SENN-ITALY U. S.-Euratom Joint Reactor Board Estimate 1960		NORMALIZED AEC "CURRENT STATUS" 1959	
Investment - $1,000	$	$/ Kw	$	$/ Kw
Land and Site Work	600	4	360	2
Building and Structures	4,000	27	7,500	50
Reactor Plant	23,100	154	18,200	121
Turbine-Generator Plant	7,700	51	10,000	67
Accessory Elect. and Main Transf.	1,300	9	1,520	10
Spare Parts	820	5	-	-
Shipping Containers	480	3	-	-
Total Direct Const. Cost	38,000	253	37,580	250
Engineering	3,780	25	3,570	24
Taxes	2,050	14	188	1
Administration Costs	6,100	41	1,730	12
Startup	1,120	7	360	2
Contingencies	1,100	7	4,340	29
Interest During Const.	8,800	59	3,960	26
Subtotal	60,950	406	51,728	344
Escalation	3,550	23	-	-
Total Generating Plant Cost	64,500	429		
Transmission Line	1,600	11	-	-
Total Investment Cost	66,100	440	-	-
First Core (Incl. Escalation)	6,400			

based on a 7 per cent annual rate with a 52 month construction schedule, whereas the AEC normalization is for a 6 per cent rate and a 36 month construction schedule. The tabulation illustrates the importance of making due allowances for variations in local conditions. It is also of interest to compare the recent estimates for the ENSI plant with anticipated costs for typical projects under the U.S. - Euratom Agreement for Cooperation. The "Three Wise Men" presented estimates for a boiling water reactor plant in their 1957 report "Target for Euratom"(9). Their estimate for investment cost was $290 per kilowatt. Similarly the U.S. - Euratom Working Group(10) estimated direct construction cost for a boiling water or pressurized water reactor plant at about $300 per kilowatt or a range of $250 to $350 per kilowatt. The corresponding investment cost, including interest during construction was estimated as $290 to $405 per kilowatt. The recent estimate for the ENSI project falls within the range of both estimates.

Table 10 compares the estimated energy costs from the ENSI plant not only with the "normalized" energy cost estimate for a 150 mwe "current status" plant but also with the 1957 estimate of "Three Wise Men" and the 1958 estimate of the U.S. - Euratom Working Group. All four estimates are consistent. It may be concluded that the ENSI project costs lie within range anticipated for U.S. - Euratom joint projects. The energy cost from a conventional plant of equal capacity is estimated as 8.6 mills per kwh.

2 - AKS Project

The AKS group of six West German utilities with headquarters in Stuttgart submitted to the U.S. - Euratom Joint Reactor Board before the October 20, 1959 deadline a proposal to build a 173 mwe nuclear plant. On January 16, 1960 AKS informed the Euratom Commission that it could not enter a firm commitment to proceed with its project primarily because of the high cost of the nuclear plant compared with the current costs of conventional power. The project was based on an organic cooled reactor to be supplied by the Interatom subsidiary of Atomics International and Germany's Demag machinery company, with Brown Boveri acting as architect-engineer and prime contractor for the conventional portion of the plant. The estimated capital investment in the plant, exclusive of fuel, as submitted to the

TABLE 10

ESTIMATES OF TOTAL ENERGY COSTS
FOR
150 MWE BOILING WATER REACTOR PLANTS

Source of Data	SENN	AEC "CURRENT STATUS"	THREE "WISE MEN"	U. S. EURATOM WORKING GROUP(1)
Date of Estimate	1960	1959	1957	1958
Rated Capacity, MWE	150	150	Not Specified	150
Plant Investment, $/Kw	440	344	290	290-405(1)
Fixed Charge Rate, %	12.7	14	13	13.3
Fuel Costs - All Costs in Mills Per Kwh				
Burnup	1.7(2)	1.8	2.1	2.3
Fabrication	1.8(2)	1.8	1.7	1.5
Fuel Inventory	0.5	0.3	0.8	0.6
Fabrication Capital	-	0.3	-	-
Chem. Process (Inc Conversion to UF_6)	0.5(2)	0.5	0.3	0.4
Transportation and Ins.	0.2	0.2	-	0.3
Plutonium Credit	-0.8	-0.8	-0.8	-0.9
Total Fuel Cycle Cost	3.9	4.1	4.1	4.2
Operating and Maint. Cost	)1.2	0.84	1.0	)2.0
Nuclear Insurance	)	0.43	(3)	)
Fixed Charges	7.5	6.9	5.4	5.5- 7.7(1)
Total Energy Cost	12.6	12.3	10.5-13.1(4)	11.7-13.9(1)

Notes:

(1) U. S. Euratom group estimate applicable to either boiling water reactor or pressurized water reactor.

(2) Fuel costs computed on assumption of standard AEC warranted fuel fabrication cost of $140 per Kg and standard warranted burnup of 10,000 MWD/metric ton.

(3) Nuclear insurance was not included in estimate but reference report indicated that provisional U. S. domestic rates for special nuclear insurance would come to about 0.2 mills per Kwh.

(4) The range was established by adding a 25 percent contingency to the estimate.

Joint Reactor Board amounted to $368 per kilowatt, but no breakdown is available.

The following energy cost estimates for the AKS project fall within the range of anticipated costs for the U.S. - Euratom joint projects.

Capital charges (12.7%)	6.7 mills/kwh
Fuel cycle cost	3.8
Operation and maintenance	0.9
Total energy cost	11.4

A load factor of 80 per cent is assumed. The energy cost from a conventional coal fired plant of equal capacity would be 9.9 mills per kilowatt hour.

3 - JAPCO Gas Cooled Plant

The Japan Atomic Power Company has purchased a 150 mwe power station of the British natural uranium gas cooled type from the GEC-Simon carves consortium for construction at Tokaimura. The supplier was selected on the basis of competitive proposals received from three British consortia each associated with Japanese firms in the electrical industry and in civil engineering. The design is similar to that for the Hunterston Station under construction by the same group for the South of Scotland Electricity Board, except that modifications were made to meet possible earthquake conditions in Japan.

A purchase contract between JAPCO and GEC was signed December 22, 1959. According to published information[11][12], the contract price is £11,825,000 plus 8.043 billion yen to be subcontracted in Japan. The dollar equivalent of the total contract price is $55.5 million equivalent to $370 per kilowatt which does not include the initial fuel charge. The total cost, including the initial fuel and direct JAPCO contracts, is reported as $97.35 million equivalent to $650 per kilowatt. The plant investment exclusive of the fuel charge is estimated to be $548 per kilowatt.

Guarantees provided in the purchase contract include:

1 - Completion of construction in 54 months.
2 - Net output of 149 mwe.
3 - Minimum thermal efficiency of 26 per cent.
4 - Fuel burn-up of 3000 mwd per ton without

reshuffling and 3880 mwd per ton with reshuffling in the equilibrium stage.

The schedule of payments for the Sterling portion of the contract is 5 per cent on signing, 25 per cent during construction and 70 per cent in 5 years after completion of construction. Interest rates are specified as 0.5 per cent above the current bank rate during the first 5-1/2 years of the contract and 1 per cent above the current bank rate during the remainder of the payment period.

The Japan Atomic Energy Commission has estimated total energy costs for the nuclear plant based on 80 per cent load factor. These are compared with estimates by the Ministry of International Trade and Industry (MITI) for a comparable conventional thermal plant.

Estimated Energy Cost in Mills Per Kwh

	Nuclear (J-AEC)	Thermal (MITI)
First year	13.9	12.1
Last year (20th)	10.0	10.8
Average	11.3	11.3

The reduction in later years is due to the decrease in interest payments as the loan is amortized. The MITI estimate is based on a fuel cost of one yen per kilocalorie (70 cents per million Btu). Other sources indicate current fuel prices in Japan are about 60 cents per million Btu based on oil from the Middle East. Anticipated import of oil from Indonesia and new contracts for Middle East oil are expected to reduce fuel costs to about 50 cents per million Btu.

D - NUCLEAR PLANTS CURRENTLY BID FOR CONSTRUCTION IN THE UNITED STATES

A number of U.S. firms are offering to build central station nuclear power plants, some on a firm price bid. For business reasons, price details of these proposals are normally not public information. Southern California Edison Company announced on April 25, 1960 that it had sent the Westinghouse Electric Corporation and the Bechtel Corporation letters of intent for the purchase of a 300 mw net electrical unit. Previous to this announcement, information was received from Westinghouse concerning price and terms of a fixed price proposal it had offered several utilities for

the same type of unit[13]. Similarly, information was received from the General Electric Company for units of 200 mw and 300 mw output which it is offering[14]. No details are available regarding associated costs of the plant. However, by using the procedures and assumptions of the AEC normalization studies modified as necessary for application to a firm price turn-key plant, a comparison can be made with an equivalent AEC "current status" plant. Both companies indicated that they felt construction and energy costs abroad would be generally comparable to those in the U.S. recognizing that local factors might raise or lower costs to some extent.

Although the exact items furnished by the prime contractor under a turn-key arrangement will vary depending on circumstances and the wishes of the purchaser, they usually can be expected to include equipment and other materials, construction and installation labor and associated engineering services. The turn-key arrangement would not include the cost of land and land rights and, while it may include site preparation, the price will vary with local conditions such as requirements for access roads, railroad connections, foundation conditions and cooling water availability.

In addition to providing the land, the utility's pre-operational expense will include the expense of administering the contract, of obtaining necessary licenses, certain sales, property and other taxes, training of operators, interest and other financial charges associated with making progress payments during construction. The total cost of interest will depend on the cost of money and the construction schedule. Also the utility's estimate will include some contingency in addition to that assumed by the contractor within his price for the portion of the plant covered by his contract, and an allowance for escalation.

1 - Westinghouse Proposal

The Westinghouse Electric Corporation has offered a 360 megawatt gross electrical output nuclear power plant with a closed cycle water cooled and moderated reactor (a pressurized water reactor with some bulk boiling in the core). It has proposed a fixed price of $68 million (subject to normal escalation and exclusive of necessary research and development costs) for a power plant constructed on a normal site, complete with main step-up transformer, ready for commercial operation. It does not include the nuclear fuel. The utility would be expected to provide the site, a railroad siding

into the site, administration of the contract, all licenses, including preparation of hazards reports with contractor assistance; training of operating personnel with Westinghouse assistance, and interest on money required during construction. Westinghouse estimates the utility's investment above the contract price at $10.4 million, bringing the total investment to $78.4 million. Based on a net output of 330 megawatts, the total investment would amount to $237 per kilowatt of which the bid price would cover $206 per kilowatt. These estimates may be compared to the AEC estimates in two ways. The total investment cost of the AEC "current status" pressurized water plant extrapolated to 330 megawatt output is $238 per kilowatt which, for all practical purposes, is identical with the Westinghouse estimate.

It is also of interest to compare direct and indirect costs separately to the extent that this can be done with the limited data available. An analysis of this sort has been prepared as part of the current study using assumptions consistent with the AEC normalization studies. The results are shown in Table 11. The Westinghouse bid price was assumed to include engineering services normally provided by an architect - engineer. Other indirect costs incurred by a utility are added using rates consistent with the AEC estimates. A contingency of two per cent is included on the overall cost of the plant rather than ten per cent used by AEC, on the grounds that the bulk of the contingency would be absorbed in the bid price. An inferred value of "Total Direct Construction Cost" was determined by adjusting for the 11.5 per cent A-E indirect costs and 8 per cent contingency assumed to be included in the manufacturer's bid price and adding the "normalized" cost of land. Thus, direct construction cost =

$$\$68,000,000 \times \frac{100}{111.5} \times \frac{100}{108} + 360,000 = \$56,820,000$$

This amounts to $172 per kilowatt compared to $174 for the direct construction cost of an AEC "current status" pressurized water plant of the same 330 mwe output. The total plant investment for the "normalized" plant based on the Westinghouse bid is $236 per kilowatt. The differences in the three estimates are not significant, in either direct cost of total investment. The only sound conclusion is that the cost estimates for AEC "current status" plants for large pressured water reactors are realistic.

Westinghouse will warrant an average fuel burn-up of 14,700 megawatt days per long ton on the equilibrium fuel cycle and has estimated energy generating costs on this basis of 7.3 mills per kilowatt hour with the

TABLE 11

ESTIMATES OF NUCLEAR POWER PLANT INVESTMENT COSTS

COMPARISON OF WESTINGHOUSE COMMERCIAL BID WITH AEC "CURRENT STATUS" PLANT

Item Description	AEC "Current Status" Est. 330 MWE (net) PWR(1) $	AEC "Current Status" Est. 330 MWE (net) PWR(1) $/Kw	Westinghouse Estimate(2) 330 MWE (Net) Closed-Cycle Plant $	Westinghouse Estimate(2) 330 MWE (Net) Closed-Cycle Plant $/Kw	"Normalized" Estimate Based on Westinghouse Bid 330 MWE (Net) Closed-Cycle Plant $	"Normalized" Estimate Based on Westinghouse Bid 330 MWE (Net) Closed-Cycle Plant $/Kw
Direct Construction Costs						
Land and Land Rights	360,000		(3)		360,000(3)	
Structures and Improvements	6,650,000					
Reactor Plant Equipment	28,500,000					
Turbine-Generator Units	18,500,000					
Accessory Elect. Equipment	1,520,000					
Misc. Power Plant Equipment	830,000					
Main Power Transformer	1,085,000					
Total Direct Construction Costs	57,445,000	174			(56,860,000)	(172) (4)
Indirect Construction Costs						
Professional Services A/E 7%	4,030,000					
Field Expense A/E 2.5%	1,440,000					
Purchasing 2%	1,150,000					
Westinghouse Bid Price	-		68,000,000	206	68,000,000	206
Adm. Cost- Client 2%	1,150,000				1,137,000	
Taxes and Ins. - Client 0.5%	288,000				284,300	
Temporary Const. Facilities - Client 0.6%	345,000				341,200	
Subtotal	69,848,000		10,500,000(3)		70,122,500	
Start-up Costs	485,000				485,000	
Subtotal	66,333,000				70,607,500	
Contingencies	(10%) 6,633,300				(2%) 1,412,200	
Subtotal	72,966,300				72,019,700	
Interest (6% Annum) 8.1%	5,900,000				5,833,600	
Total Investment Cost	78,866,300	239	78,500,000	238	77,853,300	236

NOTES: (1) Based on Report SL-1674.

(2) Based on letter from C. H. Weaver to R. L. McKinney dated March 29, 1960.

(3) Westinghouse estimate of additional utility investment omits cost of site from bid price.

(4) Inferred value based on Westinghouse bid price which was assumed to include A/E indirect costs and 8% contingency.

assumption that the plant would operate at 90 per cent load factor with annual fixed charges on investment of 12.5 per cent. For comparative purposes these assumptions have been adjusted to 80 per cent load factor and 14 per cent fixed charge rate in Table 12 which shows, also, estimates for the AEC "current status" pressurized water reactor plant at 330 mw output.

The Westinghouse proposal is understood to be contingent on performance of $4.4 million worth of research and development effort not included in the plant cost estimates. Neither the Westinghouse nor the AEC estimates include any allowance for escalation.

Insufficient information is available to analyze the fuel cycle costs. Extension of fuel life from 13,000 mwd/ton to 14,700 mwd/ton would result in a savings of about 0.2 mills per kilowatt hour if all other factors remain unchanged. The AEC projection indicates a potential fuel cycle cost for a large pressurized water reactor plant going into operation by 1966 of 2.56 mills per kilowatt hour. The 3.0 mill per kilowatt hour estimate of Westinghouse is not out of line. There is an apparent disagreement on operating and maintenance expense and nuclear insurance. These are items over which the reactor designer has little influence. They also vary from one situation to another so that conceivably both 0.5 mills per kilowatt hour as assumed by Westinghouse and 0.78 mills per kilowatt hour shown by AEC could be correct for different circumstances.

TABLE 12

Energy Cost for 330 mwe Pressurized Water Reactor Plants

	Westinghouse Estimate	"Normalized" Westinghouse Estimate	AEC "Current Status" Plant
Assumptions			
Annual fixed charge rate	12.5%	14%	14%
Plant load factor	90%	80%	80%
Fuel irradiation level	14,700	14,700	13,000
Energy Cost in Mills/kwh			
Capital cost based on $68,000,000	3.3	4.11	4.76
Utility cost capitalized at $10,400,000	0.5	0.64	
Fuel costs (equilibrium core)	3.0	3.0	3.80
Operation and maintenance			0.54
Nuclear Insurance	0.5	0.5	0.24
	7.3	8.25	9.34

2 - General Electric Proposals (boiling water reactors)

The General Electric Company has offered for sale boiling water reactor power plants in the 200 mw and 300 mw range. They have quoted both as prime contractor and as subcontractor either to the utility involved or, at his request, to a qualified engineering firm, for the nuclear steam supply system, including technical management of the project. The bid price for the plant, exclusive of land and interest during construction is approximately $230 per kilowatt for the 200 mw plant and $210 per kilowatt for the 300 mw plant, both subject to normal escalation. Table 13 compares estimates for these plants, using AEC "normalized" indirect costs with AEC estimates for "current status" boiling water reactor plants of the same output. The table shows that the proposed plants appear to have a significantly lower investment cost than the "current status" plants and are believed to be based on a design concept different from that of the dual-cycle concept which forms the basis for "current status" of technology. General Electric Company stated that they will warrant 10,000 mwd/ton to 15,000 mwd/ton fuel burn-up and quote fixed prices, subject to escalation, on fuel fabrication. In the absence of details it may be assumed that fuel cycle costs would be comparable to those estimated for AEC "current status" plants and show similar potential for future cost reductions. The $27 per kilowatt advantage of the 300 mw proposed plant over the 300 mw "current status" plant, if substantiated, would result in a saving of 0.54 mills per kilowatt hour in the cost of energy at 80 per cent load factor with 14 per cent annual fixed charge rate.

TABLE 13

ESTIMATES OF NUCLEAR POWER PLANT INVESTMENT COSTS

COMPARISON OF GENERAL ELECTRIC BIDS WITH AEC "CURRENT STATUS" PLANTS

Item Description	AEC "Current Status" Est. 200 MWE (Net) BWR 1/		General Electric Co. 200 MWE (Net BWR 2/ "Normalized" Estimate		AEC "Current Status" Est. 300 MWE (Net) BWR 1/		General Electric Co. 300 MWE (Net) BWR 2/ "Normalized" Estimate	
	$	$/Kw	$	$/Kw	$	$/Kw	$	$/Kw
Direct Construction Costs								
Land and Land Rights	360,000		360,000		360,000		360,000	
Structures & Improvements	8,748,340				10,249,800			
Reactor Plant Equipment	21,284,100				26,323,860			
Turbine-Generator Units	12,465,600				17,463,600			
Accessory Elect. Equipment	1,156,100				1,413,000			
Misc. Power Plant Equipment	583,840				702,500			
Main Power Transformer	679,500				991,000			
Total Direct Construction Costs	45,275,480	226	(38,560,000)3/	(193) 3/	57,503,760	192	(52,760,000)3/	(176) 3/
Indirect Construction Costs								
Professional Services A/E 7%	3,170,000				4,020,000			
Field Expense A/E 2.5%	1,130,000				1,440,000			
Purchasing 2.0%	904,000				1,157,000			
General Electric Co. - Bid Price	-		46,000,000	230			63,000,000	210
Administrative Cost - Client 2%	904,000		764,000		1,150,000		1,055,000	
Taxes & Insurance - Client 0.5%	226,000		192,800		288,000		263,800	
Temporary Const. Facilities - Client 0.6%	276,000		221,400		345,000		316,600	
Subtotal	51,885,480		47,538,200		65,903,760		64,995,400	
Startup Cost	417,000		417,000		476,000		476,000	
Contingency	(10%) 5,230,248		(2%) 959,104		(10%) 6,637,976		(2%) 1,300,000	
Subtotal	57,532,728		48,914,304		73,017,736		66,771,400	
Interest (6% Per Annum) 8.1%	4,670,000		3,960,000		5,920,000		5,400,000	
Total Investment Cost	62,202,728	311	52,874,304	264	78,937,736	263	72,171,400	240

Notes:

1/ Based on report SL-1674.

2/ Based on letter from R. J. Cordiner to R. L. McKinney dated March 24, 1960.

3/ Inferred value based on General Electric bid price which was assumed to include A/E indirect costs and 8% contingency.

E - CONVENTIONAL THERMAL PLANTS

1 - In the United States

The growth of the electric utility industry is reflected in the ever-increasing size of the units installed. The curve in Figure 1 shows that the average size of new units installed in the eight year period from 1950 to 1958 has increased from 40,000 kw to 124,000 kw. The projected average size unit increases to about 230,000 kw in 1965 and 340,000 kw in 1970.

As unit size increases, the cost per installed kw of generating capacity decreases as shown in Figure 2 for costs developed at the 1959 price level. These curves for coal and gas-fired units are developed for units having the most popular cycle and throttle steam conditions, i e, (a) all units under 100 mw are considered to use the non-reheat cycle while all above are reheat units, (b) throttle steam conditions are 850 psig 900F for units under 60 mw, 1250 psig 950F for units from 60 to 100 mw, 1450 psig 1000/1000F for units from 100 to 150 mw, 1800 psig 1000/1000F for units from 150 to 200 mw, 2000 psig 1000/1000F for 200 to 300 mw and 2400 psig 1050/1000F over 300 mw.

Under conditions of above average fuel costs, higher steam conditions may be economically justified. Similarly, turbine design conditions may indicate that higher steam conditions are desirable to prevent excessive exhaust blade loading.

Location of unit in a metropolitan area, as compared to one in the country, will have a marked effect on the installed cost - perhaps as much as $50 to $60 per kilowatt due to type of enclosure, circulating water facilities, fuel handling equipment and construction labor costs.

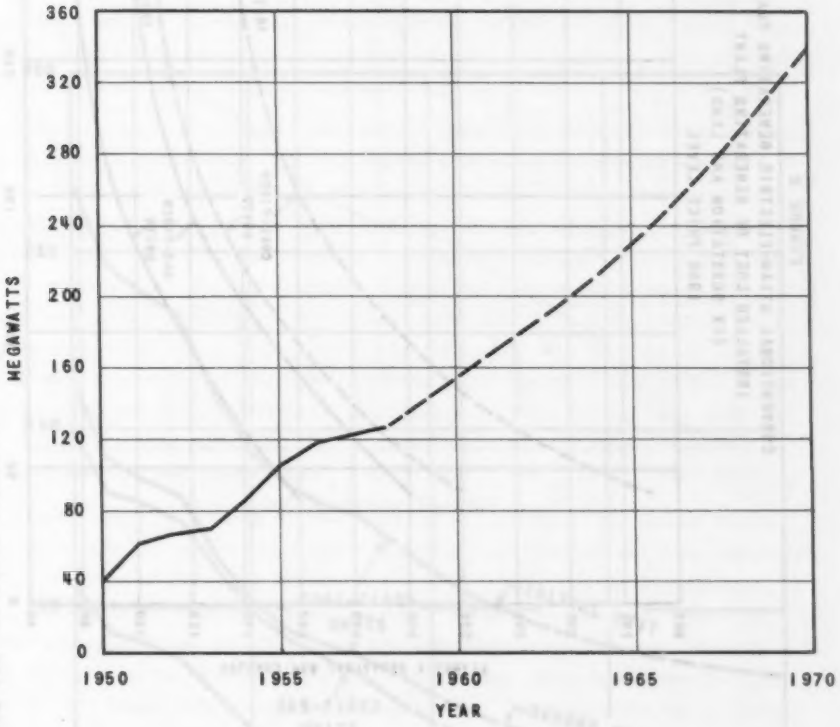
The curves in Figure 3 reflect the installed cost of the average size unit in a given year using the curves in Figures 1 and 2. As would be expected, the installed cost per kilowatt decreases since the unit size increased over the study period. However, these curves are based on 1959 price level and thus are not indicative of the cost per kilowatt of new capacity installed in each year.

To adjust the generating plant costs shown in Figure 3 to date of installation, the curve in Figure 4 showing relative steam-electric plant cost increases since 1950 was prepared by analysis of increases in the level of selling prices of turbine-generators, steam generators and other material and equipment up to

FIGURE 1

CONVENTIONAL STEAM-ELECTRIC GENERATING PLANT

AVERAGE SIZE OF NEW UNITS



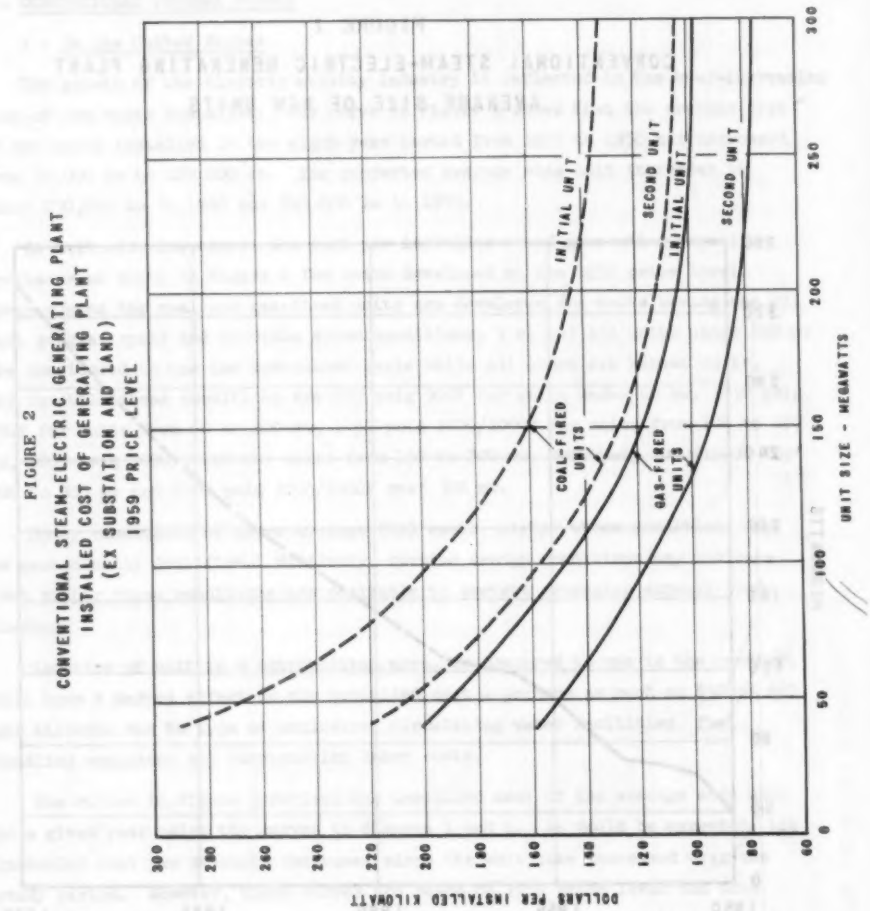


FIGURE 2
CONVENTIONAL STEAM-ELECTRIC GENERATING PLANT
INSTALLED COST OF GENERATING PLANT
(EX SUBSTATION AND LAND)
1959 PRICE LEVEL

FIGURE 3

CONVENTIONAL STEAM-ELECTRIC GENERATING PLANT
INSTALLED COST OF GENERATING PLANT
(EX SUBSTATION AND LAND)
1959 PRICE LEVEL

BASED ON AVERAGE SIZE UNIT INSTALLED
IN EACH YEAR AS SHOWN IN FIGURE I

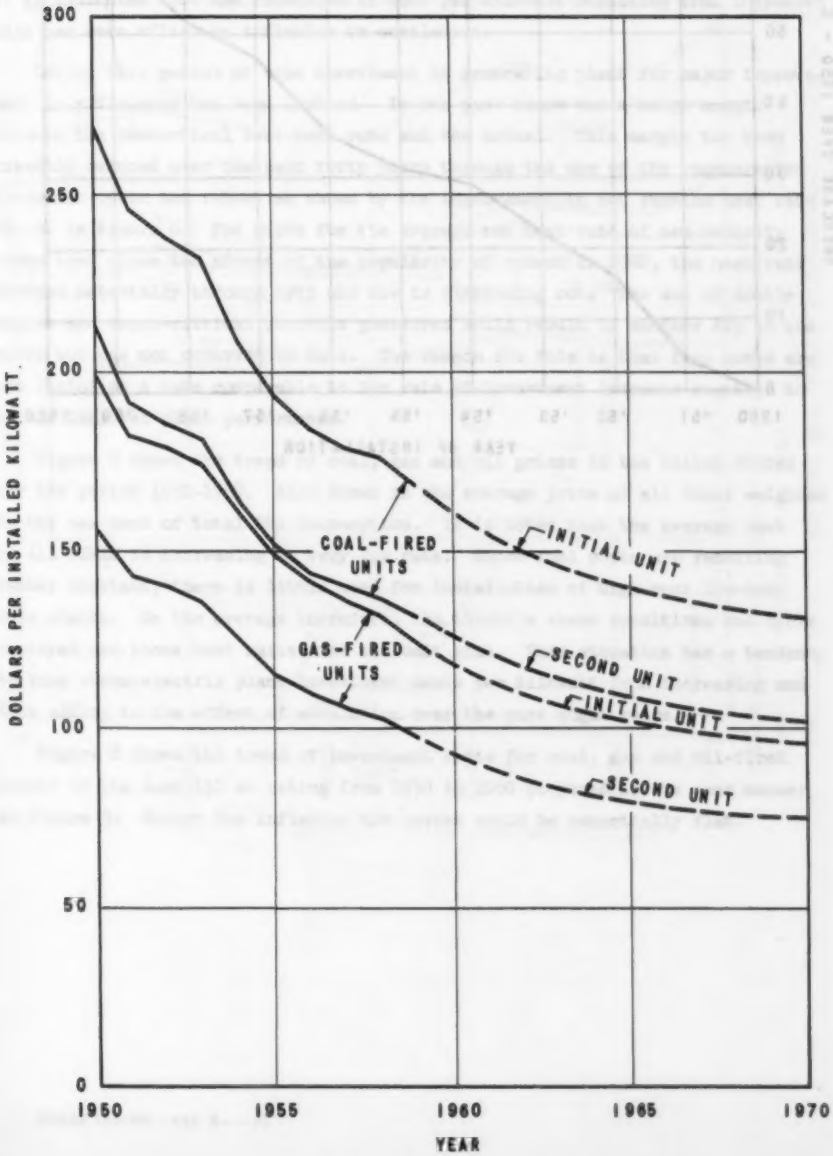
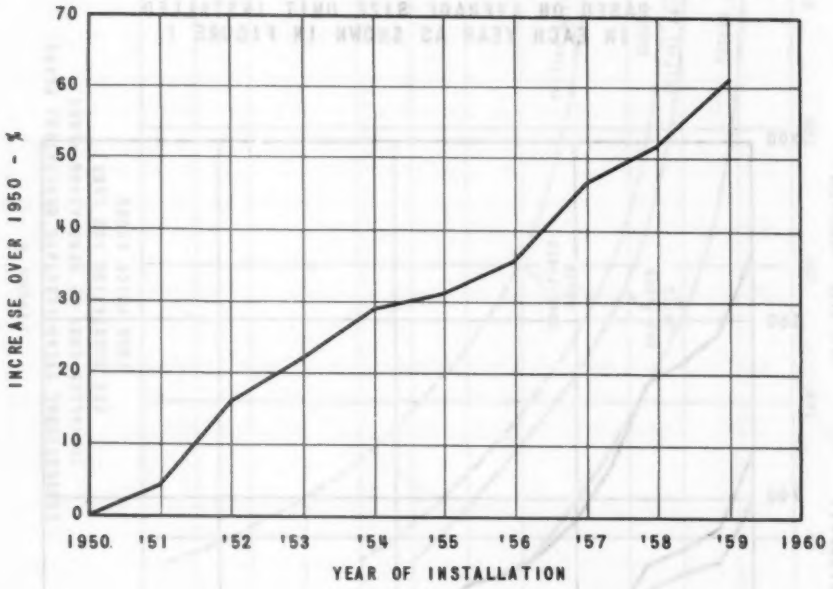


FIGURE 4

CONVENTIONAL STEAM-ELECTRIC GENERATING PLANT
COST INCREASES SINCE 1950



date of purchase, plus escalation from date of purchase, to shipment of equipment. Also included is the effect of estimated increase in construction labor and material costs.

Using the cost increase curve in Figure 4 to adjust the cost of the average size unit installed each year shown in Figure 3 at the 1959 price level results in the curves shown in Figure 5. These cost curves show the cost per kilowatt of installed capacity for the average size unit at the price levels prevailing at date of installation. It is noted that the cost per kilowatt of installed generating capacity has remained ratner constant in the past eight years. Thus it is indicated that the reduction in cost per kilowatt resulting from increased size has been offset by inflation or escalation.

During this period of time investment in generating plant for major improvement in efficiency has been limited. In the past there was a large margin between the theoretical best heat rate and the actual. This margin has been steadily reduced over the past forty years through the use of the regenerative feedwater cycle and reheat as shown by the improvement in net station heat rate curves in Figure 6. The curve for the average net heat rate of new capacity shows that since the advent of the popularity of reheat in 1948, the heat rate dropped materially through 1955 and now is flattening out. The use of double reheat and super-critical throttle pressures could result in another dip in the curve but has not occurred to date. The reason for this is that fuel costs are not rising at a rate comparable to the rate of investment increase required to obtain improved plant performance.

Figure 7 shows the trend of coal, gas and oil prices in the United States for the period 1952-1958. Also shown is the average price of all fuels weighted by the per cent of total Btu consumption. It is noted that the average cost of all fuels is increasing at very low rate. Since fuel costs are remaining rather constant, there is little need for installation of high-cost low-heat rate plants. On the average therefore, the throttle steam conditions and cycle employed are those best suited for the unit size. This situation has a tendency to keep steam-electric plant investment costs per kilowatt from increasing and thus adding to the effect of escalation over the past eight years.

Figure 8 shows the trend of investment costs for coal, gas and oil-fired plants of the same 150 mw rating from 1950 to 1960 prepared in the same manner as Figure 3. Except for inflation the curves would be essentially flat.

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FIGURE 5

CONVENTIONAL STEAM-ELECTRIC GENERATING PLANT
INSTALLED COST OF GENERATING PLANT
(EX SUBSTATION AND LAND)
PRICE LEVEL AS OF DATE OF INSTALLATION
BASED ON AVERAGE SIZE UNIT INSTALLED
IN EACH YEAR AS SHOWN IN FIGURE I

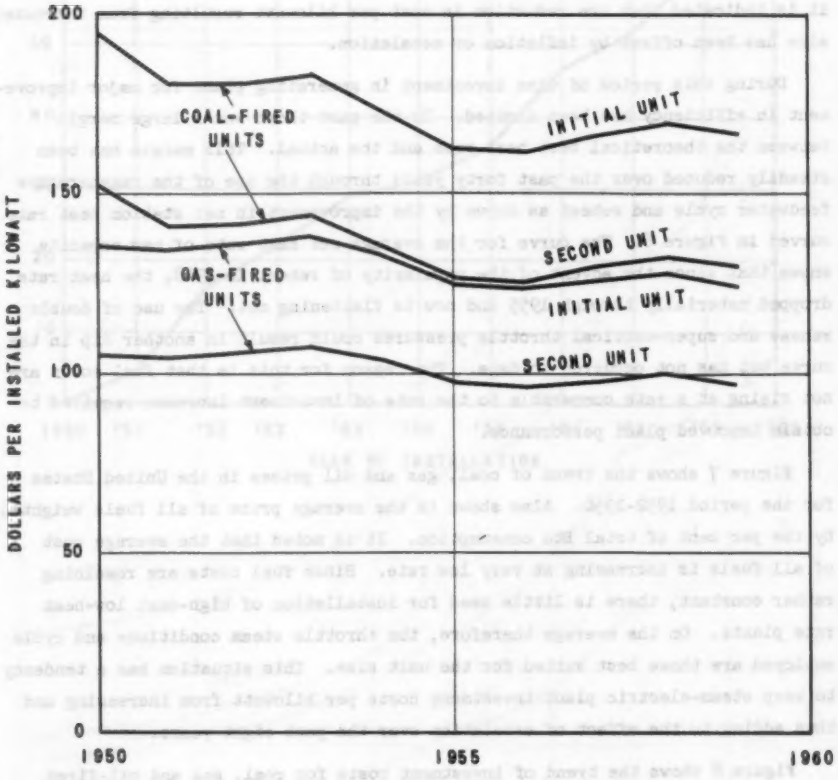


FIGURE 6

CONVENTIONAL STEAM-ELECTRIC GENERATING PLANT
NET STATION HEAT RATE

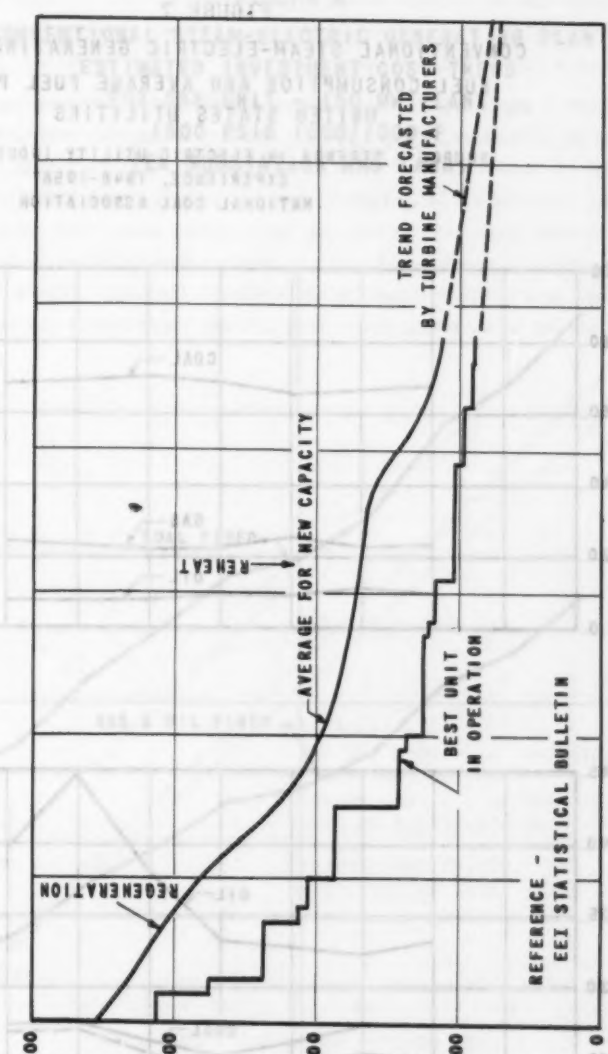


FIGURE 7

CONVENTIONAL STEAM-ELECTRIC GENERATING PLANT
FUEL CONSUMPTION AND AVERAGE FUEL PRICE
UNITED STATES UTILITIES

SOURCE - "TRENDS IN ELECTRIC UTILITY INDUSTRY EXPERIENCE, 1946-1958"
NATIONAL COAL ASSOCIATION

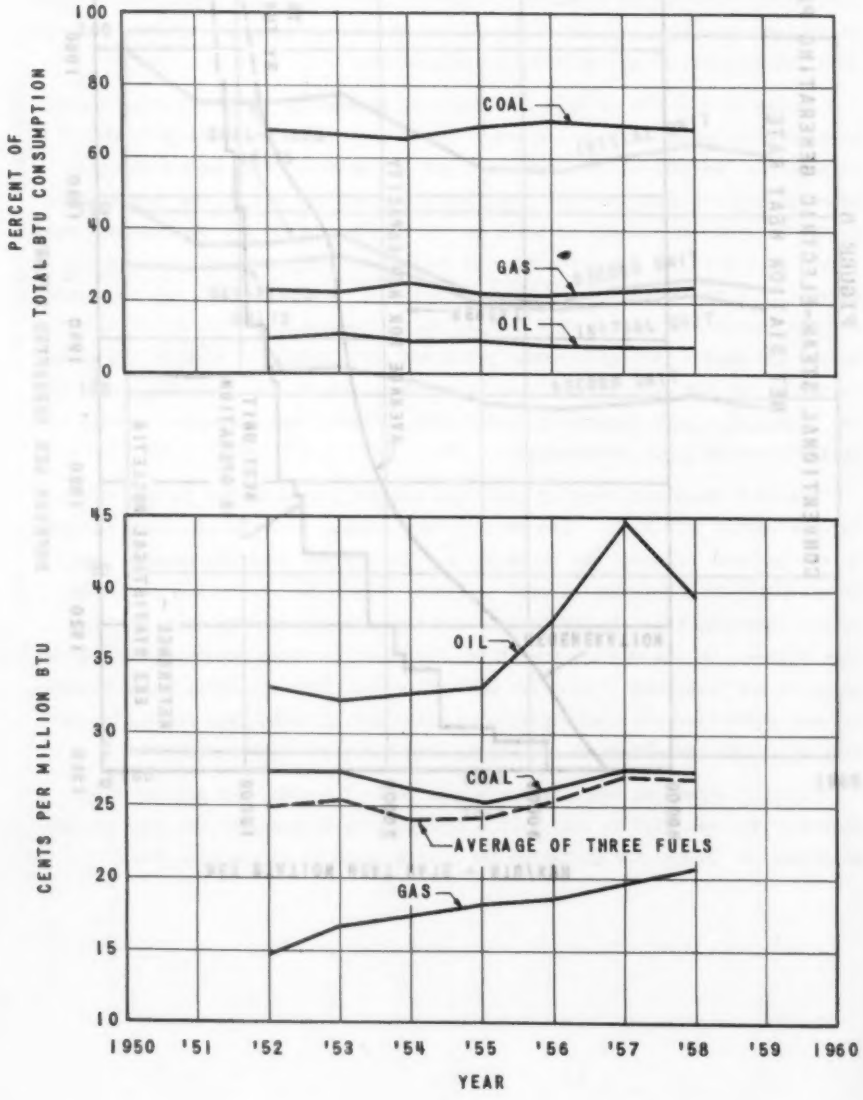
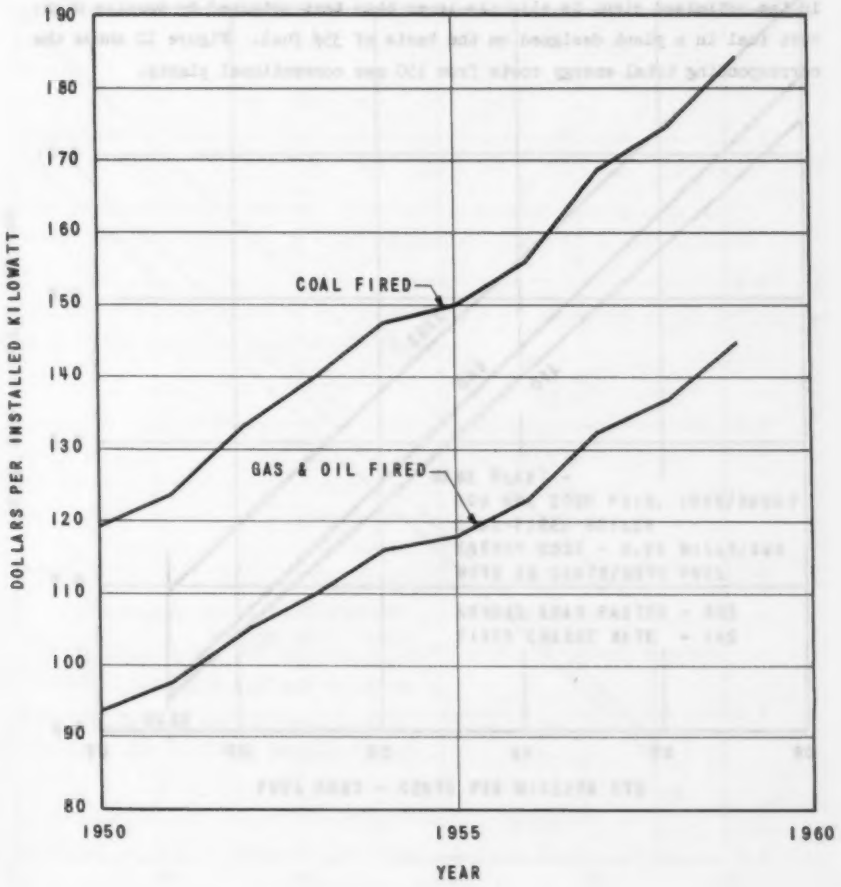


FIGURE 8

CONVENTIONAL STEAM-ELECTRIC GENERATING PLANT
ESTIMATED INVESTMENT COST TREND
FOR ONE UNIT - 150 MW PLANT
1800 PSIG 1000/1000 F
(EX SUBSTATION AND LAND)



Technology has not changed during the ten-year period. In constant dollars the optimum plant for a given situation would have essentially constant cost. In practice costs will vary with fuel costs and with location.

Figure 9 shows total energy costs from 300 mwe plants burning coal, oil and gas as a function of fuel price. The curve for coal coincides with the estimate of Report SL-1564[3] at a coal cost of 35 cents per million Btu. However, for substantially higher coal costs the optimum plant will be one with somewhat higher efficiency and hence higher cost. The overall energy cost in the optimized plant is slightly lower than that obtained by burning high cost fuel in a plant designed on the basis of 35¢ fuel. Figure 10 shows the corresponding total energy costs from 150 mwe conventional plants.

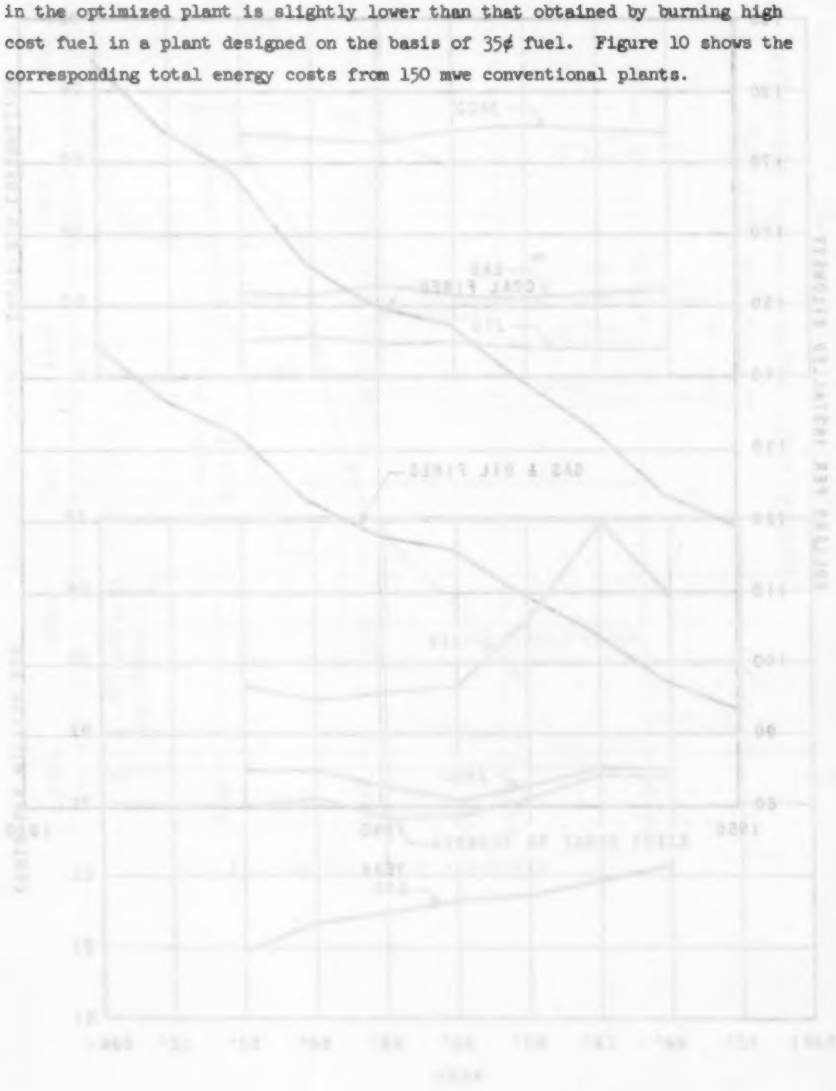


FIGURE 9

CONVENTIONAL STEAM-ELECTRIC GENERATING PLANT
ENERGY COST
(INCLUDING FIXED CHARGES)
ONE UNIT - 300 MW PLANT

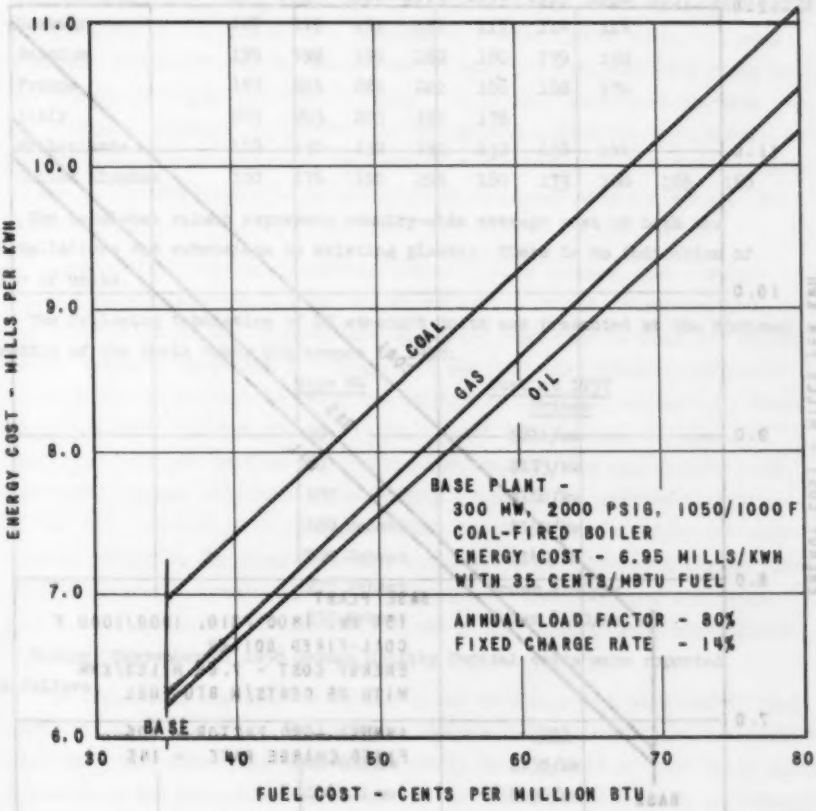
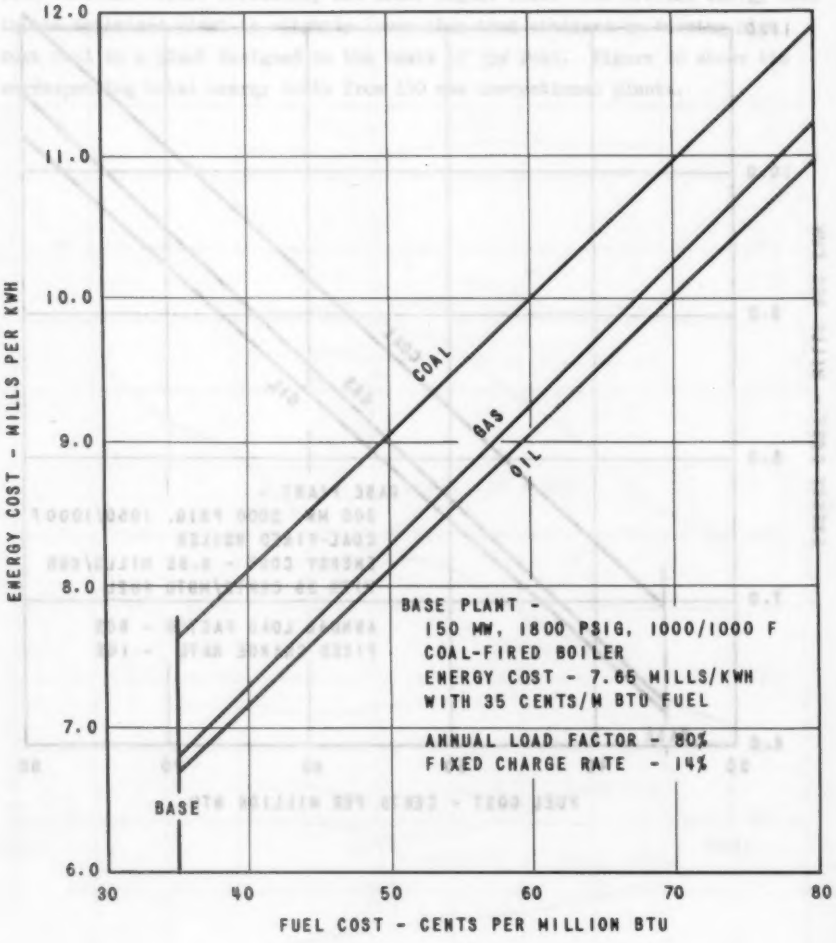


FIGURE 10

CONVENTIONAL STEAM-ELECTRIC GENERATING PLANT
ENERGY COST
(INCLUDING FIXED CHARGES)
ONE UNIT - 150 MW PLANT



2 - Abroad

Information on plant investment costs outside the United States is rather meager.

The following tabulation is excerpted from the report of the OEEC Electricity Committee on "The Electric Supply Industry in Europe"(20).

Capital Outlay on Thermal Plant (Production only)
(Cost in dollars per kilowatt)

Country	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959
Germany	107	119	131	121	117	114	114			
Belgium	199	199	199	180	180	179	150			
France	157	214	229	229	186	186	174			
Italy	203	203	203	192	176					
Netherlands	118	132	132	132	132	138	144			
United Kingdom	160	176	190	194	180	173	168	165	160	

The tabulated values represent country-wide average cost of both new installations and extensions to existing plants. There is no indication of size of units.

The following tabulation of UK standard units was presented at the Montreal meeting of the World Power Conference in 1958:

Size MW	Cost at 1957 Prices
30	$211/kw
60	$173/kw
100	$162/kw
120 Reheat	$152/kw
200 Reheat	$140/kw
275 Reheat	Under $140/kw
550 Reheat	Under $140/kw

During September of 1958 German Utility Capital costs were reported as follows:

Unit Size	Cost
400-600 mw	$135/kw
100-200 mw	$150/kw
10-15 mw	$165/kw

Current estimates for oil burning thermal plants in Japan indicate a cost of approximately $200 per kilowatt for the initial unit of a plant of ultimate capacity of 1000 megawatts and $160 per kilowatt for extension units.

Construction costs in most European countries and Japan are not much different from those in the US.

V - MAJOR FACTORS AFFECTING COSTS OF ENERGY FROM NUCLEAR PLANTS

A - CAPITAL CHARGES

1 - Rates of Charge

The annual financial charges on investment have a particularly strong influence on the economic attractiveness of nuclear power relative to conventional plants and also on the relative attractiveness of alternate reactor concepts. Because nuclear power is characterized by inherently low fuel costs and inherently high investment costs, favorably low fixed charges improve the competitive position of nuclear power vis-a-vis conventional power and tend to favor reactor concepts with low fuel costs at the expense of higher investment costs. It is this consideration that makes natural uranium gas cooled reactors attractive in the U.K. where annual fixed charge rates are typically 8.4 per cent and much less attractive in the U.S. where fixed charge rates of 12 to 14 per cent are typical for private utilities.

Financial charges on investment include, as a minimum, the cost of money or investment capital and the amortization of the investment over the life of the plant. Appropriate allowance must also be made for income taxes, property taxes and insurance. In the U.K. the nationalized power industry is not subject to taxes and an applicable fixed charge rate based on 5½ per cent interest and twenty year plant life amounts to an annual charge of 8.37 per cent on the initial investment. The appropriate rate for most European utilities is comparable to rates for private utilities in the U.S. It should be recognized that the actual rate varies not only between utilities but also with time for a given utility depending on its ability to raise capital for new construction. Evaluation of a nuclear plant for a specific situation should use a fixed charge rate appropriate for that situation.

In evaluating the cost of nuclear power in comparison with fossil fuel power, it has been common practice to exclude the necessary fuel inventory from the plant investment and to include it in estimates of fuel cycle costs. Inasmuch as the corresponding investment in conventional fuel is relatively small this practice permits a convenient comparison between the plant construction costs for conventional and nuclear plants and between conventional fueling costs and the equivalent cost of substituting nuclear fueling. However, in considering the financing of a new plant a utility must take

into account the sizeable investment in nuclear fuel element fabrication which may be as high as $40 to $60 per kilowatt. The AEC use charge for enriched uranium may be paid out of revenues since it is incurred concurrent with operation. The fabricated fuel elements are consumed and their loss in value charged during operation so that a lower fixed charge rate is justified for the continued investment in initial and replacement fuel cores than for the depreciable plant investment.

2 - Load Factor

It has been common practice to evaluate nuclear plants at a relatively high load factor. The primary reason is that with relatively high investment costs a high load factor is essential if a nuclear plant is to compete with a fossil fired plant in the near future. There is added justification, however, in the fact that a nuclear plant, if it is to compete at all, will have lower fuel costs than a fossil fired plant, and hence would be preferred for base load. Furthermore, many of the improvements in fuel cycle cost for new nuclear plants can be applied to existing plants so that obsolescence will be less rapid. Accordingly, a nuclear plant would be suitable for base load operation for a longer time than has been the past experience with conventional plants. Nevertheless, when a major part of the system capacity is represented by nuclear plants, the current practice of keeping units with lowest operating costs on the line will dictate that older nuclear plants will be relegated to supplying peak demand.

To be acceptable for utility operation, nuclear power plants must be designed for high reliability and to meet requirements for base load operation. Availability of 80 per cent or more is virtually essential. It is quite reasonable to assume that a carefully designed plant could achieve a load factor of 90 per cent or more if required by system demands. This implies that unanticipated difficulties which might be encountered are eliminated. Such "bugs" occur all too frequently in conventional plants and there is no reason to assume that a nuclear plant is immune to them. Thus, less than optimum load factor may be experienced during the start-up or breaking-in period. To assume that any plant, nuclear or conventional, will actually operate at 90 per cent load factor over its entire useful life does not seem to be realistic.

In Part II of its report (2) AEC tabulated the annual plant factors for the 11 largest U.S. steam-electric stations during 1957. The load

factor for these plants ranged from 42 per cent to 96 per cent with a combined average of 80 per cent. It is interesting to note that the same 11 plants averaged 75 per cent load factor the following year. Also, the plants with exceptionally high load factor are those supplying the large steady AEC diffusion plant requirements. Undoubtedly, certain individual units in the listed stations operated at load factors significantly higher than the station as a whole. However, information for individual units in multi-unit stations cannot be derived from the Federal Power Commission reports used in preparing the table.

In its evaluation for commercial stations, the UKAEA has assumed a load factor of 75 per cent on the basis that they will operate as base load plants. A major goal of the U.K. program is to develop nuclear plants which will be competitive at the lower load factors which will eventually obtain when the amount of nuclear capacity installed exceeds the base load on the electricity generating system. The OEEC study[15] assumes a load factor of 75 per cent for evaluation purposes.

Some conventional thermal plants are specifically designed for peak load operation. In such cases, emphasis is placed on low plant investment at the expense of somewhat higher fuel costs. Plants with such characteristics are frequently built to firm up systems predominantly supplied by hydro plants or systems for which at least part of the base load is supplied by thermal units. It is common practice to use older units for peaking purposes while new units installed for meeting load growth are designed for optimum fuel costs under base load conditions. Nevertheless, some utilities are finding it economical to install relatively large modern units specifically designed to supply peak loads rather than to use old small and relatively inefficient units. At some time, it may be desirable to install a nuclear plant to supply peak loads. The AEC estimates indicate that organic cooled reactors may be potentially useful for this purpose, but the economics of the particular situation would have to be examined before reaching a definite conclusion.

3 - Escalation

The AEC estimates do not include escalation, hence are based on 1959 dollars. While inflation is not inevitable it must be recognized that indices of thermal power plant construction costs in the United States have risen an average of 3 to 4 per cent per yer respectively from about 1948 to July 1959. (16) The rate of change during the latter half of 1959 was significantly less. However, the prudent utility operator will assume that similar increases can occur in the future. If one could assume that inflation would affect all costs - investment, fuel and operating costs equally, relative costs would bear the same relation as if escalation were ignored. However, plant investment costs are subject to escalation only during the construction period, whereas fuel and operating are subject to escalation throughout the operating life of the plant in addition to the construction period. Furthermore, if a nuclear plant requires three to four years for construction and a conventional plant can be completed in less time by a year, the former is subject to a higher percentage increase during a period of rising costs. No criticism of AEC procedures is intended because estimates of escalation are speculative. However, vendors' quotations either on whole plants or components are normally subject to price adjustment. Evaluation of a particular plant for a particular situation will properly include an allowance for price escalation to arrive at actual cost expectancy. It is not clear that comparable assumptions as to escalation are always made for the conventional plant to which a nuclear plant is compared.

B - NUCLEAR FUEL CYCLE COSTS

Nuclear fuel cycle costs include the cost of fissionable material consumed, taking appropriate credit for fissionable uranium and plutonium values in the spent fuel, the cost of fabricating or otherwise preparing fresh fuel elements, the cost of reprocessing spent fuel, the cost of shipping spent fuel and the cost of providing the necessary fuel inventory including lease charges and financing charges for purchased fuel materials and fabrication. The several factors contributing to fuel cycle costs are discussed below.

1 - Natural Uranium Price

Natural uranium is normally purchased. AEC estimates assume that the cost of any purchased natural uranium used in fuel elements is part of the fuel element fabrication cost. The price paid by AEC for uranium ore or natural uranium concentrate (U_3O_8) contributes to its cost for enriched uranium. Hence, changes in the cost of natural uranium should affect fuel cycle costs for enriched reactors as well as for natural uranium fueled reactors. The trend of uranium concentrate prices has been downward. This is illustrated by the following table based on published AEC data. (17)

AEC PROCUREMENT COST FOR CONCENTRATE IN DOLLARS PER POUND OF U_3O_8

Fiscal Year	1956	1957	1958	1959	1960
Domestic Procurement	11.96	10.80	9.76	9.40	8.95*
Foreign Procurement	10.94	11.18	11.18	11.12	-
Average	11.35	11.00	10.63	10.34	-

Source: US AEC Annual Financial reports for 1957, 1959

* Six month figure (July to December 1959)

AEC Release C-50 (March 25, 1960) shows average price paid of $8.79 per pound. The tabulated value was adjusted for AEC expenses assumed to be in the same proportion as 1959.

In the future, the cost of domestic ore will have greater influence on AEC costs which may stabilize between $8.00 and $8.50 per pound. Note that the AEC base price for concentrate from domestic mills is $8.00 per pound, effective through December 31, 1966. This would represent a reduction of 25 to 30 per cent from the 1956 cost prevalent at the time the AEC price schedule was announced. A reduction of 25 per cent in the

current price of natural uranium can be considered as a possibility. This would result in approximately 0.3 to 0.4 mills per kilowatt hour reduction in fuel cycle costs for a 300-mw reactor burning natural uranium as the principal fuel.

2 - Enriched Uranium Prices

The present AEC schedule of charges for enriched uranium was announced in November 1956. In addition to the reduction in cost of natural uranium feed, the operating efficiency of the diffusion plants has probably improved over the years and should continue to improve. It is quite likely that reductions in the base price for enriched uranium will be made in the next five to ten years. A reduction in the cost of enriched uranium will affect the use charge for the fuel and the depletion cost. Presumably, the credit for plutonium would also change proportionately. A 25 per cent reduction in the cost of enriched uranium would decrease the fuel cycle cost in large power stations by approximately 0.35 to 0.65 mills per kilowatt hour, depending on the particular reactor concept, if plutonium value remains at $12 per gram. If plutonium credit is assumed to be proportional to enriched uranium value, the effect of a 25 per cent reduction in enriched uranium cost would amount to 0.25 to 0.58 mills per kilowatt hour in the fuel cycle cost.

On the other hand, AEC's cost of enriching uranium is based on certain favorable conditions. The tremendous capacity installed for producing military material leads to maximum operating efficiency. If the production rate were to be drastically curtailed to supply power plant needs the unit cost would rise. Similarly, if a new plant were constructed on a commercial basis solely for power plant requirements, the production cost would probably be significantly higher. Finally, the AEC plants enjoy exceptionally favorable electricity costs. The cost of electrical energy represents roughly 40 per cent of the present enrichment cost of separative work, or between 15 and 20 per cent of the final cost of enriched product. Thus, any significant reduction in enriched uranium prices, or even a continuation of present prices, implies continuous availability from AEC diffusion plants and a continuation of present policies.

3 - Plutonium Price

The fuel value of plutonium is determined by its value as a substitute for enriched uranium as a power reactor fuel. If all reactors had the same characteristics, the proper fuel value of plutonium would be such that it would have no effect on energy costs. There would be no market for plutonium if its cost, as burned, were higher than the cost of enriched uranium. On the other hand, if its cost were lower the operator would recycle his own plutonium as more economical than procuring enriched uranium. However, some reactor types can make use of plutonium more effectively than others and hence the fuel value of plutonium would be determined by its value in reactors making most effective use of it (assuming the distribution of number and types of reactors in operation provided a balance between supply and demand). Even so, the cost of burning plutonium can be no higher than the cost of burning enriched uranium in such more efficient reactors.

It is not possible to predict the distribution of reactor types and the resulting supply and demand situation which will determine the actual fuel value of plutonium at any particular time in the future. The current value of $12 per gram established by the AEC is based on judgment of what the future value may be. With "current status" technology, it is more expensive to use plutonium costing $12 per gram, either as original or recycle fuel, than to use uranium. Hence currently planned reactors will produce an excess of plutonium over the demand for power reactor fuel. Even under the AEC definition of "economic potential," estimates show the use of plutonium at $12 per gram is unfavorable. This does not necessarily mean that the $12 per gram value is too high because the technology of burning plutonium is not sufficiently advanced to assess its real potential. However, unless reactor technology is developed which will permit economic use of plutonium, it may be necessary to reduce the plutonium price to avoid the accumulation of undesirable stocks of surplus plutonium. On the other hand the $12 per gram fuel value of plutonium is low enough to encourage long irradiation of fuel, there being little or no incentive to settle for less than the maximum attainable burn-up for the sake of plutonium credit.

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This situation would not necessarily persist if fuel fabrication and processing prices could be drastically reduced. On balance, the $12 per gram fuel value for plutonium appears to be reasonably consistent with established AEC charges for enriched uranium. In the long term, the plutonium value should not change greatly. The AEC considered the effect which a 50 per cent change upward or downward in plutonium value would have on the fuel cycle cost for its "current status" estimates as shown in Table 14. The change ranges from 0.3 to 0.8 mills per kilowatt hour depending on reactor type.

Table 14

EFFECT OF PLUTONIUM PRICE ON FUEL CYCLE COST (MILLS PER KWH)

Plutonium Credit	$12/g	$6/g	$18/g
Reactor Type			
Pressurized Water	3.81	4.35	3.27
Boiling Water	3.47	3.87	3.07
Organic Cooled	5.72	6.20	5.24
Sodium Graphite	4.12	4.38	3.86
Gas Cooled, Enriched	3.59	4.07	3.11
Fast Breeder	7.10	7.81	6.39
D_2O Moderated	4.22	4.99	3.45

4 - Uranium Inventory Cost

AEC evaluations have been based on a standard annual lease charge of 4 per cent of the value of enriched fuel. In the event that enriched uranium were purchased rather than leased, the user would incur financial charges appropriate to the investment. Depending on circumstances, this may vary from the cost of borrowed money to a combination of equity and borrowed capital augmented by income taxes and perhaps by ad valorum taxes. Even if material is leased to a foreign government at the AEC 4 per cent rate, the ultimate user may have to pay an additional service charge. The appropriate rate may thus vary from 4 per cent as assumed in the AEC studies to 12 per cent or even higher.

Under the terms of the US-Euratom Agreement and the Atomic Energy Act of 1954, as Amended, enriched uranium may be transferred to Euratom on a deferred payment purchase basis, whereby only interest at a rate of 4 per cent per annum is paid for the first ten years of operation and thereafter payments are made for an additional ten-year period of equal annual installments covering the value of the inventory and interest at 4 per cent per annum on the unpaid balance.(17) According to these terms, the annual payments by Euratom would be 4 per cent of the initial value of the fuel inventory during the first ten years of operation and 12.33 per cent during the second ten-year period. If Euratom or its member States imposes no surcharge, these charges would be passed on to the operating utility. It may be assumed that the utility would employ the same method of financing the deferred purchase as it would if the inventory were purchased at the outset. Thus, it might pay 4 per cent annually out of revenues for the total 20-year period and finance the additional payments with borrowed capital, thus borrowing at 8.33 per cent of the value of the inventory each year from the 11th to the 20th year.

If the utility is fortunate enough that it can finance indebtedness at 6 per cent per annum, the deferred payment plan should cost no more than 4.5 per cent, on the average, over the 20-year period and even less if a sinking fund is established during the first ten years of operation to meet higher payments during the latter ten years. If the net cost of financing indebtedness is as high as 12 per cent per annum, the average annual cost for the 20-year period is 6 per cent or less. It may not be advisable to use a sinking fund in view of the fact that other fuel cycle costs should decrease over the life of the plant. Of course, after the expiration of the 20-year period required to complete deferred payments, the cost of maintaining the fuel inventory is the same as if the fuel inventory were purchased at the outset.

The following table compares, under various assumptions of average annual rate appropriate to lease, purchase or deferred payment, the cost in mills per kilowatt hour of fissionable material inventory for 150 mwe plants of the pressurized water, boiling water and organic-cooled reactor. The deferred payment adds at most about 0.3 mills per kilowatt hour during the 20-year period compared to lease at 4 per cent, whereas purchase adds four times as much.

TABLE 15

EFFECT OF FUEL PURCHASE RATHER THAN LEASE

Case	A	B	C	D
Average Annual Rate	4%	4.5%	6%	12%
Cost of Fuel Inventory in Mills/Bwh				
Pressurized Water Reactor	0.55	0.62	0.82	1.65
Boiling Water Reactor	0.28	0.30	0.42	0.84
Organic-Cooled Reactor	0.57	0.64	0.85	1.71

Case A corresponds to lease at 4 per cent, available to US operators.

Case B corresponds to deferred payment purchase, with 6 per cent cost of money.

Case C corresponds to purchase, with 6 per cent cost of money or deferred payment purchase, with 12 per cent cost of money.

Case D corresponds to purchase, with 12 per cent cost of money.

It may be concluded that acceptance of the deferred payment arrangement results in a significant cost saving over immediate purchase of the fuel inventory. Unless Euratom or the utility's home government imposes an excessive surcharge on the AEC charges for the material the average fuel inventory cost over the 20-year purchase period is only moderately higher than that incurred under a lease arrangement at 4 per cent annual use charge.

5 - Fabrication Costs

The AEC Status Report assumes the following unit fabrication costs in dollars per kilogram of uranium for the several ractors considered:

Reactor	Fuel Material	Clad	Fabrication Cost ($/kg)
BWR	UO_2	Zr	140
PWR	UO_2	SS	110
OCR	U-3.5% Mo	Al	60
SGR	U-10% Mo	SS	110
FBR	U-10% Mo	Zr	480

The Fast Breeder Reactor core elements are small (1/6 in. diameter) pins compared to roughly 1/3 in. diameter for others.

The cost includes the cost of making the oxide or alloy from UF_6, shaping, jacketing, assembly, supply of component materials, AEC charges for lease of fissionable material during the fabrication operations and material losses, and scrap recovery costs. The costs are relatively high

because of low volume, lack of mechanization, protection against accidental criticality and other health and radiation hazards, and rigid testing and quality control. There is room for substantial cost reductions if the volume of requirements for fuel elements of a given type is sufficiently high. At the same time, the first core cost for a novel type may exceed the listed values.

Fuel elements for UK reactors are supplied by the UKAEA. So far as power stations in the UK are concerned the price is negotiated between the respective Electricity Board and the AEA. Since both are government agencies, this price is of little interest to other fuel users. For export, UKAEA will supply fabricated fuel elements for £ 17,000 per metric ton ($47.60 per kg). This includes the cost of the natural uranium content as well as fabrication. The UK cost of uranium has not been revealed. However, if concentrate costs $10 per pound of U_3O_8 corresponding to $26 per kilogram of uranium, the cost comparable to US fabrication costs is about $21.50 per kilogram, including reduction of the oxide.

6 - Capital Cost of Fuel Fabrication

Inasmuch as a full loading of fabricated fuel elements must be on hand prior to start-up of a reactor, the operating utility must provide some means of financing the cost of fabrication which is normally payable on delivery. Financial charges will vary with the ability of the utility to obtain the necessary funds. It may be possible to finance the fabrication with a bank loan with perhaps a small additional cost for insurance, but this may not always be the case. In its normalized study, the AEC assumed working capital for this purpose would be obtainable at 6 per cent per annum and calculated the cost of financing the fuel fabrication at this rate, assuming the investment represented by fabrication included half the cost of fabricating a full charge plus the average inventory of spare elements. This is an exceptionally low rate for working capital, which is frequently charged at a rate comparable to that for plant investment less amortization, and sometimes at the full rate charged for plant investment.

The cost of financing fuel fabrication as estimated by AEC is in the range of 0.2 to 0.3 mills per kilowatt hour for most "current status" plants. The actual cost may be as much as three times as high in some circumstances.

7 - Processing

The main problem in undertaking spent fuel processing on a commercial basis is the uncertain processing load. In the early years of a nuclear power industry, the processing requirements will be relatively small, in terms of material handled as compared to most industrial chemical operations, and intermittent. The trend toward longer fuel life, as necessary for reducing fuel cycle costs, aggravates the situation since fuel may stay in the reactor up to four or five years without replacement.

The AEC schedule for processing changes is based on estimated costs for a hypothetical plant. The AEC plans to process spent fuel elements it accepts in existing processing plants as they can be scheduled, but the actual recovery cost will have no bearing on the charge made.

The AEC reference plant is assumed to process 1000 kg per day of spent uranium and the charges are based on operation 300 days per year. This capacity could service more than 15 nuclear plants of 150 mwe with a fuel burn-up of 12,000 mwd/t.

The base charge announced by AEC in 1957 amounted to $15,300 per day. This was computed for the reference plant design to include operating costs and 10 per cent annual depreciation of the plant. No allowance was made for financing costs which, including taxes could run to 12 to 20 per cent of the plant investment annually. The AEC charge includes a 15 per cent administrative overhead.

R W Klotzback [18] estimated that the same plant built and operated under normal commercial practices would entail a daily cost of about $36,600. Several studies have been made by private industry of the feasibility of building an economic plant for processing nuclear fuel. Studies completed to date have been negative. However, a new study is underway by the Davison Chemical Company, in conjunction with five utility companies.

The $15,300 per day charge is subject to adjustment for labor and material costs. Two such adjustments have subsequently been made, and the current charge is $16,440 per day, although costs in the AEC Status Report are based on the original rate. The 8 per cent increase experienced in two years time would increase energy costs for organic and water-cooled reactor types by 0.03 to 0.05 mills per kilowatt hour.

8 - Chemical Conversion Costs

The currently used processes for chemical recovery produce uranium and plutonium in the form of the respective nitrates, whereas the standard forms for AEC pricing schedules are uranium hexafluoride and plutonium metal. The AEC has issued a schedule of charges for converting recovered material to meet standard specifications. This amounts to $5.60 per kilogram of uranium in enrichments up to 5 per cent U-235 and $1.50 per gram of plutonium.

9 - Transportation

The AEC normalization studies include a shipping cost for fresh fuel amounting to $3 per kilogram of uranium and a shipping cost of $12.45 per kilogram for spent fuel. This results in a cost of approximately 0.2 mills per kilowatt hour for fuels irradiated to more than 10,000 mwd per metric ton and up to about 0.6 mills per kilowatt hour when fuel irradiation was limited to 3000 mwd per ton. Shipment of fuel elements overseas would increase this cost.

10 - Irradiation Level

The relatively high fabrication and processing costs for nuclear fuel elements provides a strong incentive to extend the irradiation as much as possible to extract the maximum amount of energy from each pound of fuel fabricated and processed. There has been insufficient actual experience in long term irradiation of fuel elements to determine definite exposure limits on a statistical basis. There is laboratory evidence that fuel exposures longer than assumed in the AEC study can be realized. Only experience can prove how conservative the estimates are in this respect.

Fuel life may be determined by any one of three factors:

a - Corrosion of fuel jackets, under operating conditions, to the point that intolerable amounts of fission products are released to the coolant. The type and rate of corrosion is determined primarily by temperature, coolant purity and coolant velocity with some influence by radioactivity. Fuel life as limited by corrosion is mostly a matter of time of exposure at temperature rather than of megawatt days of operation. Most reactors can tolerate a limited amount of cladding failure before fuel replacement is necessary.

b - Irradiation damage to the fuel material resulting in intolerable distortion (warping, swelling etc.), impairment of heat transfer or release of fission gases whose pressure could distort or rupture the fuel jacket. Uranium metal and high uranium alloys are limited to relatively low exposure levels (roughly 3000 to 5000 mwd/t depending on temperature and alloy composition) due to swelling and fission gas release. In water cooled reactors, the consequence of fuel jacket failure is aggravated by the chemical reactivity between the metal and water, although certain alloying additions may reduce the reaction rate. Uranium oxide (UO_2) has been irradiated to levels exceeding 50,000 mwd/t with negligible dimensional change. UO_2 has the advantage for water cooled reactors of being inert toward water, so that cladding failure is less serious. However, it is not inert to some other coolants, notably sodium, and has relatively poor thermal conductivity. Uranium carbide (UC) has higher thermal conductivity than UO_2 and shows promise of good high temperature performance, particularly in sodium and gas cooled reactors, and reasonable cost.

c - The reactivity life of the fuel which can be increased within wide limits by increasing the initial enrichment. Such a practice may introduce problems in controlling the initial high reactivity and, generally, increases the fuel inventory and burnup costs. Natural uranium normally is limited in reactivity

to about 3000 mwd/t, but can be improved by shuffling fuel elements to perhaps a maximum of 7000 mwd/t in heavy water cooled reactors. Thus, natural uranium fuel is generally termed "reactivity limited," whereas the life of enriched fuel is more likely to be limited by the integrity of the materials used. Reactivity may of course be augmented by "seeding" or "spiking" with enriched uranium or plutonium.

The AEC studies assume that an average fuel exposure of 18,000 - 19,000 mwd/t would be feasible for UO_2 or UC fuels by about 1970. This leads to significantly lower fuel costs from the "present status" plants with 11,000 - 13,000 mwd/t.

The British gas-cooled reactors of the Calder Hall type use metallic natural uranium with Magnox (magnesium-beryllium alloy) jackets. This fuel is limited by reactivity to about 3000 mwd/t without reshuffling or perhaps 3800 mwd/t with reshuffling. A major reduction in fuel cycle costs requires substitution of UO_2 for longer life and an alternate jacket material (beryllium is the current choice) for higher temperature. Since the substitution of UO_2 reduces the initial reactivity, the longer life made possible by UO_2 cannot be realized without also resorting to some enrichment. The British hope to keep the enrichment below 1 per cent, which accounts for interest in the low neutron absorption of beryllium. However, when the fuel cycle is optimized there is not likely to be much difference in either technology or fuel cycle costs between US and UK reactors.

11 - Warranties

US fuel fabricators and reactor manufacturers are willing to warrant a minimum exposure in thermal megawatt days per ton for fuel elements which they supply. The usual warranty provides that fuel elements which fail to meet the specified minimum exposure will be replaced, subject to a pro-rated charge for the fraction of the warranted exposure which is realized. As a rule, the supplier cannot assume liability for contingent damage or loss of reactor output during an unscheduled outage. The warranty is no different in this respect than the usual warranty on equipment. Admittedly, the reactor operator may incur other expenses in the event that some fuel elements fail to meet the warranted exposure. One such expense recognized in the US Euratom Agreement is an added cost for premature chemical processing, including extra shipping charges. (19) The US government agrees to enter

into an arrangement by which it would assume this added cost, provided savings, if any, on subsequent fuel elements which exceeded the minimum warranty were shared up to the original outlay. Similarly, the US government offers to underwrite warranties of exposure and fabrication price for proven fuel elements in the event the US supplier could not meet specified minimum warranties. The Euratom operator is thus assured some measure of protection against excessive fuel cycle costs. At the same time, the fuel elements are normally conservatively designed, from the standpoint of reactivity lifetime, and also from the standpoint of fuel element integrity to the extent that the latter can be predicted. Accordingly, there is a fair probability that the warranted burn-up will be exceeded and lower energy costs result.

Normal equipment warranties are offered by reactor or nuclear power plant suppliers. These include attainment of specified power output by the plant, continuous operation at rated power for a specified number of hours and perhaps a specified net heat rate (Btu/kwh).

The UKAEA have offered to sell fabricated natural uranium fuel elements suitable for the gas-cooled reactors offered by the consortia at a fixed ceiling price of £ 20,000 per metric ton ($56 per kg) until approximately 1970. Current prices are £ 17,500 per metric ton. A burn-up guarantee, generally between 3000 and 3500 mwd per ton, is provided as well as an agreement to buy back spent fuel elements at a negotiated price schedule depending on degree of burn-up.

C - OPERATING AND MAINTENANCE COSTS

Too little operating experience for full-scale nuclear power stations exists to determine the magnitude of operating and maintenance expense. At the present stage of development, it is to be expected that operating and maintenance costs for a nuclear plant would be somewhat higher than for a conventional plant. However, the difference should not be more than a few tenths of a mill per kilowatt hour except for unusual items such as make-up of heavy water or organic coolant.

After examining operating requirements for the several reactor types, the AEC normalization studies concluded that a total station staff of 70 would be required for a single-unit station of 50 to 100 megawatt capacity and 95 for a single-unit station of 150 to 350 megawatt capacity. The corresponding payroll, including fringe benefits, would amount to about 0.36 mills per kilowatt hour for a 300 mwe station and about 0.54 mills per kilowatt hour for a 150 mwe station, both operated at 80 per cent load factor. Ordinary maintenance materials and services will vary somewhat with different reactor types, ranging from about 0.25 mills per kilowatt hour for the simple reactors with water, organic or gas coolant to about 0.35 for a thermal sodium-cooled reactor and about 0.45 mills per kilowatt hour for a fast sodium reactor, and possibly as high as 2.0 mills per kilowatt hour for an aqueous homogeneous reactor. The cost in mills per kilowatt hour of maintenance materials and services is very slightly higher for a 150 mw reactor than for a 300 mw reactor of the same type.

The cost of replenishing organic coolant amounts to about 0.5 mills per kilowatt hour based on a make-up rate of 25 pounds per thermal megawatt day at 13.5 cents per pound, while the cost of heavy water make-up equivalent to 3 per cent of total inventory per year at $28 per pound amounts to 0.3 to 0.35 mills per kilowatt hour in plants of 300 to 150 mw.

Overall operating and maintenance expense ranges from about 0.6 to 1.0 mill per kilowatt hour for a 300 mwe plant operated at 80 per cent load factor and about 1.0 to 1.4 mills per kilowatt hour for a 150 mwe plant according to the AEC estimates for "current status" plants. These estimates appear to be reasonable. The corresponding operating and maintenance expense for a coal-fired plant would be about 0.4 to 0.5 mills per kilowatt hour on the same basis.

D - NUCLEAR INSURANCE COSTS

Insurance costs for nuclear plants represents a significant cost item and is substantially higher than for conventional plants. The Price-Anderson Act provides financial protection for installations in the U.S. against a disastrous nuclear incident at a modest cost. Legislation to provide similar protection is in process in Japan and European countries. However, premiums for private insurance coverage of nuclear liability and on-site property damage are high at present due to lack of experience and insufficient spread of risk owing to the relatively small number of installations requiring coverage. It is the hope of both the utility industry and the insurance industry that premium rates can be drastically reduced in the future.

The AEC normalization studies for "current status" plants assumed an all-risk nuclear property insurance at a rate of 35 cents per $100 of insurance coverage (assumed to be equal to the total plant investment) in addition to appropriate nuclear liability up to the maximum of $60,000,000 offered by stock and mutual insurance pools. With these assumptions, the total cost of nuclear insurance ranges from 0.25 to 0.33 mills per kilowatt hour for 300 mw plants and 0.40 to 0.46 mills per kilowatt hour for 150 mw plants at 80 per cent load factor.

In a statement written in response to a questionnaire prepared by the Atomic Industrial Forum, Willis Gale, Chairman, Commonwealth Edison, stated:

> "At our 640,000 kilowatt Ridgeland conventional station our insurance costs are 0.001 cents per kilowatt hour. For our Dresden station, we have been budgeting insurance costs which will equal 0.05 cents per kilowatt hour, or fifty times as great. This, of course, is a considerable hurdle for atomic power to overcome. Moreover, we have recently been informed that the premium may be even higher. We have taken this problem up with the insurance industry and have hopes that something will be done to keep the costs within reason".

VI - TECHNICAL CONSIDERATIONS

A - LIGHT WATER COOLED REACTORS

The lowest energy costs from nuclear plants in the next few years is likely to result from the use of reactor types for which the technology has been relatively well advanced. In the United States considerable effort has been expended in developing reactor technology based on light water cooling. This stems in part from the use of water cooling for the production reactors at Hanford and later in naval propulsion reactors. For both of these applications, light water cooling was chosen after careful consideration of other concepts.

Light water offers several advantages for central station power plants. Normally, it is relatively cheap and readily available. There is a general familiarity with it in the power field as a result of long and intimate experience. Reactor systems based on its use are relatively simple. In a light water reactor the core can be quite compact and be designed for a high negative temperature coefficient of reactivity which enhances inherent safety.

Light water cooled and moderated reactors are generally classified as pressurized water reactors and boiling water reactors. The latter have the advantages of generating steam in the reactor for use directly in a steam turbine, thereby eliminating the heat exchanger used in the pressurized water reactor, and of reducing the ratio of reactor pressure to turbine throttle pressure. The most advanced concepts of pressurized water reactors would permit some boiling in the reactor, even some net steam generation. At the same time, certain boiling reactors (dual cycle and indirect cycle) make use of intermediate heat exchangers similar to those associated with pressurized water reactors. Hence, the presence or absence of boiling within the reactor is of secondary importance. The principal distinguishing feature is whether or not steam derived from the primary coolant is used directly in the turbine. If it is, as in boiling water, or direct cycle, reactors, the turbine and condensate system will be radioactive during normal operation and must be designed accordingly. In other respects the technology is essentially the same for both types, except that reactor control characteristics may be quite different.

According to the AEC studies, both pressurized water and boiling water reactors are limited by current technology to a maximum of approximately 300 megawatts net electrical output by the size of the pressure vessels. Estimated plant construction costs are not greatly different for the two types. It is not obvious which would be cheaper. In this connection, it should be noted that design variations are possible for each type. Actual cost will vary with the specific design chosen and with the particular manufacturer or designer of the reactor system. Both pressurized water and boiling water reactors can use the same basic types of fuel elements. The preferred fuel material is UO_2. Jackets of either zircaloy or stainless steel may be used. The overall fuel cycle cost can vary more with individual design and manufacturing facilities and procedures than with choice of cladding material. On the basis of current technology,no clear advantage is apparent for either type of fuel element for either type of reactor. Optimum fuel cycle costs may be very nearly the same for either concept.

The principal disadvantages of water as a reactor coolant are its corrosive effects on structural material and its relatively high vapor pressure. Both properties become troublesome at elevated temperatures. Not only does corrosion affect the integrity of the cooling system, but the accumulation of fission products in the coolant may interfere with heat transfer, or coolant flow, by depositing on heat transfer surfaces or other locations in the coolant system. Both of these effects have presented problems in conventional steam systems which have required special alloys in boilers, turbines and piping. Extensive water treatment has been necessary to control corrosion to reach steam temperatures employed in modern thermal plants. Corrosion and pressure are largely responsible for present limits on steam temperature which can be raised only after additional problems are solved. These problems are aggravated in nuclear reactors, first, because it becomes necessary to limit the quantity of otherwise desirable materials to avoid excessive neutron absorption and,second, because certain corrosion products become seriously radioactive, thereby increasing shielding requirements for coolant circulating loops and adding to the difficulty of maintenance operations. Furthermore, most corrosion inhibitors commonly used in conventional steam plants are unsuitable for use in a reactor either because they are decomposed under irradiation, or because they add to the radioactivity of the coolant or adversely affect the neutron economy by excessive neutron absorption.

In a pressurized or boiling water reactor three major limiting effects are traceable to high vapor pressure. In the first place, the maximum coolant temperature is determined by the reactor pressure. In a simple boiling water reactor, the temperature can be no higher than that corresponding to saturation at the reactor pressure. If boiling is suppressed as in the pressurized water reactors, the coolant temperature must be somewhat lower than saturation. In either case, saturated steam proves to be most economical in spite of the fact that the cost of large turbines designed for superheated steam are generally cheaper for a given rating. Secondly, high pressure tends to limit maximum reactor power. The cost and difficulty of fabricating, shipping and installing the reactor vessel increases substantially with increasing diameter. Thirdly, reactor containment requirements are determined largely by the amount of high pressure water stored in the reactor system which could be released by a reactor incident. Accordingly, water cooled reactors can be expected to have the most severe containment requirements. The high vapor pressure of water increases the possibility of a fuel element meltdown resulting from loss of coolant in the event of a primary system rupture.

Because of the apparent limitations on water-cooled reactors, based on current knowledge, there is incentive to develop other reactor types. Nevertheless, there is no reason to believe that water-cooled reactors are reaching the end of their potential. Just as has been the case with conventional steam plants, improvements can be expected which cannot be identified today. It is by no means clear that water-cooled reactors will not continue to be competitive with other types. It is clear that no other type today rests as firmly on proven technology. In all probability, the utility industry of the future will employ more than one type of reactor to achieve optimum economy in utilization of nuclear fuel and to meet various load requirements. Light water cooled reactors show excellent promise of assuming and maintaining an important position in the utility industry even though other types are developed to the point of economic competition.

B - NUCLEAR SUPERHEAT

One limitation of water cooled reactors, namely, limited steam temperature, can be removed by the successful development of methods of superheating steam in the reactor. The principal advantages of superheated steam are higher thermal efficiency and lower cost turbine equipment. The feasibility of nuclear superheating has been demonstrated in a tube inserted in the Vallecitos Boiling Water Reactor and also in an experimental reactor in the USSR. The Borax-V reactor experiment will investigate nuclear superheating. The boiling water reactor under construction for the Pathfinder Nuclear Station in Minnesota will incorporate nuclear superheating as will the BONUS project for construction in Puerto Rico.

Nuclear superheating of steam involves a somewhat different technology from that of pressurized water and boiling water reactors, although the superheating region may be an integral part of a pressurized or boiling water reactor. Direct superheating of steam is equivalent to cooling fuel elements with a gas. Compared to fuel elements for cooling with liquid or boiling water, the superheater elements must meet severer service conditions and may be more expensive. The power density of superheating region can be expected in general to be lower than in the boiling region. Accordingly, pressure vessel size limitations probably will limit power output for a reactor with an integral superheater. Finally, control problems are aggravated for an integral superheater. Appreciable research and development effort is required for application of nuclear superheat to water cooled reactors. The potential economic advantage has been estimated as about 0.7 mills per kilowatt hour for a 300-mw power plant.

C - ORGANIC COOLED REACTORS

Hydrocarbons as a class are similar to light water in nuclear properties because they have nearly the same hydrogen density. In general, they are much less corrosive to common structural materials than water. However, they are more readily decomposed by high temperature and radiation and have poorer heat transfer properties. Sufficient work has been done to demonstrate that the polyphenyl series of hydrocarbons have adequate resistance to thermal and radiation damage at temperatures as high or higher than 700 F, for practical power reactor use. The Organic Moderated Reactor Experiment (OMRE) has been operated at the National Reactor Testing Station in Idaho since 1957 to demonstrate the feasibility of cooling reactor with polyphenyl materials.

A second experimental Organic Cooled Reactor (EOCR) is being design for further extensive research on organic cooling. No attempt is made to generate electricity with either OMRE or EOCR. The first organic cooled power plant is under construction at Piqua, Ohio. It is scheduled to go into operation late in 1961.

The outstanding advantage of organic cooled reactor is the inherently low plant capital cost. This stems from several factors. Organic cooled reactors have low corrosion rates which permit the use of relatively inexpensive materials for the reactor vessel and primary coolant loop. They have low radioactivity in the primary coolant. Due to relatively low vapor pressure of the organic coolant the reactor vessel and primary coolant loop may be designed for approximately 100 lb per square in. pressure rather than 1000 to 2500 lb per sq in. as required by boiling water and pressurized water reactors. They have higher steam temperatures and resulting higher thermal efficiency when compared to water cooled reactors. Their low capital cost is offset in part by the need for continual replenishment of the polyphenyl coolant which adds about 0.6 mills per kilowatt hour to the cost of energy under conditions of presently expected price for organic coolants and the temperature and radiation conditions of current design concepts.

The major uncertainty of organic cooled reactors is in the fuel cycle cost, and more specifically in the demonstration that a cladding material with adequate integrity can be developed. Neither zircaloy nor stainless steel, which are the preferred materials for water cooled reactors, appears to be suitable. Zirconium suffers from hydride formation due to contact with the organic coolant at high temperature. Stainless steel has relatively low thermal conductivity, which is objectionable in the finned jackets needed to compensate for the organic coolant's poor heat transfer properties. The relatively large amount of stainless steel in the fins would also be undesirable because of excessive neutron absorption. Aluminum is satisfactory from a corrosion and heat transfer point of view but has poor creep strength at the desired operating temperature. Aluminum can be used for cladding, provided the fuel material has sufficient strength to support itself without transmitting loads to the cladding. Uranium alloyed with 3.5 per cent molybdenum has adequate strength but its resistance to radiation damage has not been established, although samples have been irradiated to 3300 mwd/t without distortion. Although UO_2 is the preferred fuel material for long fuel life, an element composed of UO_2 pellets would not support an aluminum jacket at the desired temperatures.

A material which shows considerable promise for organic reactor fuel cladding is a sintered aluminum alloy incorporating a substantial amount of aluminum oxide which imparts high temperature strength. This material, of recent origin, can be extruded with fins, has relatively high thermal conductivity and appears to be otherwise suitable for use in polyphenyl coolants up to 900 F. Experience with the material is limited. An intensive development program will be required to demonstrate its performance as a reliable fuel element cladding.

D - GAS COOLED REACTORS

Gas cooled reactors have certain advantages over water cooled reactors. Their coolant temperatures, and hence steam temperatures, are not related to reactor pressure. Their corrosion effects may be less important, depending on the choice of coolant gas.

The United Kingdom nuclear power program is oriented toward the development of natural uranium gas cooled reactors for central station use. To some degree, the choice of gas cooling is an outgrowth of the British plutonium production program which turned to air cooling initially in part because the United Kingdom is limited in sites with abundant cooling water as at Hanford. The dual purpose Calder Hall and Chapel Cross stations were a natural extension of Windscale technology and have proved so successful that plants with an aggregate electrical capacity of nearly 2 million kilowatts are committed for construction utilizing a modest extension of the same technology. The use of natural uranium metal in the United Kingdom fuel elements was originally dictated by a lack of enriched uranium, but it resulted in fuel elements which are relatively cheap to fabricate. Although the corresponding plants are more expensive to construct than water cooled plants, the low financial charges required on utility capital in the United Kingdom leads to favorable overall economics.

The natural uranium fuel elements are clad in finned jackets of Magnox, a magnesium alloy, and cooled with carbon dioxide. The principal temperature limitation is the central metal temperature which indirectly limits steam temperature to about 650 F. The currently assumed limitation on fuel burn-up is about 3000 megawatt days per ton based on metallurgical damage, because there is insufficient experience to assure that it can be exceeded.

The reactivity of natural uranium is sufficient for a fuel life of about 5500 megawatt days per ton. As will be discussed later, the fuel life limitation is important in determining fuel cycle costs.

A logical improvement in performance of gas cooled reactors is the substitution of UO_2 for uranium metal, since this will permit both longer fuel life and higher steam temperatures. Taking full advantage of UO_2 in extending fuel life requires some enrichment and a major increase in gas temperature requires replacement of Magnox with a better high temperature material. The British are developing an Advanced Gas Cooled Reactor (AGR) which will use UO_2, slight enrichment and beryllium (or stainless steel) cladding. A prototype AGR of 28 mwe is under construction at Windscale for completion in 1961 and commerical plants based on this concept should be available after 1965.

The development of gas cooled reactors has lagged in the United States because the natural uranium type has not been as attractive, economically, as water cooled reactors, with construction costs and capital charges prevailing here. United States thinking has been that the real potential of gas cooled reactors lies in obtaining substantially higher gas and steam temperatures. A 22.3 mwe Experimental Gas Cooled Reactor is being designed for construction by the AEC at Oak Ridge. This reactor will use enriched UO_2 clad in stainless steel. The coolant will be helium and a gas temperature of 1050 F at 300 psia is planned. Gas temperatures as high as 1200-1300 F are anticipated in future reactors. Helium is preferable for high temperature reactors because of the serious reaction between carbon dioxide and a graphite moderator at temperatures above 950 F.

The High Temperature Gas Cooled Reactor project supported by a group of utilities for construction of a prototype plant at Peach Bottom, Pa., is aimed at the development of a reactor using graphite clad elements of uranium and thorium carbides dispersed in graphite. The objective is to obtain very high gas temperatures. The British program also includes work on a high temperature gas-cooled reactor (HTGC) using dispersion type fuel and gas temperatures up to 1380 F. An experimental reactor of 20 thermal megawatts is planned for construction at Winfrith Heath. The OEEC is participating in this so-called Dragon project and exchange of information between AEC and UKAEA on high temperature gas cooled reactors is planned.

E - SODIUM COOLED REACTORS

Sodium-cooled reactors permit steam temperatures much closer to those used in modern utility plants than do water-cooled reactors. Sodium has excellent heat transfer properties and has a low vapor pressure at temperatures of interest. The corrosion rates of steels, zirconium, uranium, thorium and their alloys as well as uranium carbide are extremely low in pure sodium at least up to 1200 F. However, small amounts of oxygen and other impurities promote mass transport of metals, leading to possible fouling of heat transfer surfaces, plugging of small coolant passages and accumulation of radioactive contamination in equipment. Sodium reacts violently with water to form hydrogen which introduces a possible fire or explosion hazard. Sodium has a melting point of 207 F and precautions must be taken to prevent or control freezing. Neutron irradiation produces 15-hour Sodium-24. Accordingly, the primary coolant loop is intensely radioactive during reactor operation and must be shielded. The consequences of a sodium-water reaction are enormously magnified if the sodium is radioactive. Hence, many plant designs include an intermediate heat exchange loop of non-radioactive sodium to transport heat from the primary coolant to the steam, while others resort to special features, such as double tube sheets, to minimize the possibility of contact between sodium and water.

Sodium-cooled reactors are at an economic disadvantage in smaller sized units because extra equipment and complexity needed for handling of sodium in even the smallest plant leads to relatively high plant construction costs. As the size is increased, the better efficiency provided by high quality steam leads to greater economy. Since the reactor vessel for sodium need only withstand modest pressure there is no problem in increasing its size as is the case with the water-cooled reactors. Very high power output should be feasible.

Sodium cooling may be used in reactors with a thermal, intermediate or fast neutron spectrum according to the relative amount of moderator employed. A very fast neutron spectrum is desirable for maximum breeding ratio with plutonium fuels but leads to extreme compactness with difficult engineering problems associated with heat removal. A thermal reactor has lower neutron economy but somewhat easier heat removal and can use low enrichment uranium. Intermediate energy reactors represent somewhat of a compromise in compactness,

reactor costs and fuel cycle costs, but the optimum neutron energy varies with the type of fuel material. It is not possible now to determine what type of sodium-cooled reactor will produce the lowest cost energy nor to determine how important breeding or high conversion ratio will become at any particular time in the future.

Much of the coolant and fuel element technology is common to thermal, intermediate and fast sodium-cooled reactors and parallel development programs would be complementary. Sodium-cooled reactor experience in the US includes the EBR-1, a reactor experiment cooled with sodium-potassium alloy utilizing a very fast spectrum in a demonstration of high conversion ratio, the Sea Wolf submarine propulsion plant and its earlier land-based prototype, both using berylium moderator to provide an intermediate neutron spectrum, and the Sodium Reactor Experiment (SRE) as a test of a thermal neutron reactor with graphite moderator and low enrichment uranium. Sodium-cooled power plants under construction include the graphite moderated thermal unit at Hallam, Nebraska, the fast neutron unit in the Enrico Fermi Station of Detroit Edison Company, and the EBR-II at the NRTS in Idaho. The United Kingdom's 60 mw(t) sodium-potassium cooled fast reactor at Dounreay, Scotland reached criticality in November 1959. The USSR has operated a 5 mw fast reactor.

Component development is an important part of sodium coolant technology because of the novelty of using this material under expected conditions. Further development of pumps, valves, heat exchangers, etc is required to achieve mechanical reliability at low cost. Sodium heated steam boilers and superheaters are particularly important since they require materials which must be compatible with both sodium and high temperature water and steam.

Fuel elements remain a problem from an economic point of view. Uranium metal alloys are limited in fuel burn-up at temperatures required for economic operation. The low thermal conductivity of UO_2 limits heat transfer rates otherwise possible with a sodium coolant. Uranium monocarbide (UC) appears to have properties well suited to sodium-cooled reactors, but very little data have been developed on this material. The carbide has better thermal conductivity than UO_2 and on the basis of preliminary data appears to have favorable fuel burn-up possibilities and an acceptable cost. The potential of UC for this application must be demonstrated.

F - HEAVY WATER REACTORS

The principal advantage of heavy water reactors is that the low neutron absorption of heavy water makes the use of natural uranium feasible. However, the fuel life with natural uranium is limited by reactivity. Therefore, the most economic fuel cycle probably requires some enrichment or, alternatively, recycle of plutonium. Much development work on heavy water power reactors has been carried out in the United States as an extension of Savannah River technology. A prototype reactor is under construction by the Carolinas-Virginia Nuclear Power Associates. Serious consideration is being given to a gas cooled heavy water moderated reactor by the East Central and Florida West Coast Utility Groups. Nevertheless, the most advanced development of heavy water power reactors is that of the Canadian program which includes a 20 megawatt demonstration plant (NPD) under construction and a 200 megawatt station at Douglas Point for which construction will start in mid-1960, as well as development work for an organic cooled heavy water reactor.

The NPD reactor, which is of the pressure tube type, will use UO_2 pellet fuel, clad in zircaloy. The Canadians expect to achieve 10,000 mwd per ton with natural uranium oxide in large reactors by proper fuel management. If burn-ups of this order of magnitude are achieved, the most economic fuel cycle is expected to be one in which no chemical reprocessing would be performed.

The cost of heavy water inventory and make-up is an expense item not found in other reactors. Plants designed to minimize losses of heavy water will be somewhat more expensive to build. Nevertheless, the potentially low fuel cycle cost, together with a relatively low fixed charge rate appropriate to Canadian utilities, tends to balance the higher investment cost to give an estimated over-all energy cost which is attractively low.

G - OTHER REACTOR TYPES

Many other reactor types are possible, including modifications of types now under active development and distinctly different types. Some of these may prove to be economical for central station application at some stage of utility development. Some, like the aqueous homogeneous reactor, may be potentially useful when depletion of fuel resources makes breeding desirable. Nevertheless, none appear capable for at least ten years of generating electricity at costs significantly lower, if as low, as types that are close to application now.

H - THERMONUCLEAR REACTORS

The development of controlled thermonuclear power generation can be divided into three phases:

Phase 1 - The development of sufficient knowledge in the field of high energy plasma physics to permit the construction of a device that can contain and maintain a plasma at or above the ignition temperature (for DT reaction the ignition energy is about 6 Mev while the DD reaction requires about 53 Mev).

Developments to date have been substantial. Ionic energies of the order of 1 Mev have been demonstrated in dense plasmas. High energy injection techniques have been developed. Containment periods significantly longer than the period required for the onset of hydromagnetic instabilities have been demonstrated. As knowledge increases it seems probable that in the near future the attainment of the ignition temperature for the DT reaction will be achieved. The attainment of the high temperature needed for ignition of the more economically desirable DD reactors is more remote in time and is less assured.

Phase 2 - The design and construction of a pilot plant to demonstrate the generation of useful power from an ignited plasma.

The solutions to this problem are far more complicated than the associated physics problems which are at present under study. These problems cannot be attacked until the work of Phase 1 has demonstrated the ultimate method for attaining the required ionic energies.

Phase 3 - Determination of the economics of the process.

This phase lies in the far future.

The following table furnished by the AEC indicates the level of effort as of the end of 1959:

Country	Manpower	Cost (Millions of dollars)
United Kingdom	150	6.0
France	60	2.5
Germany	110	2.0
Remainder of Europe	154	2.4
Total Free Europe	474	12.9
USA (Project Sherwood)	347	38.0

Russia and East Germany - unknown. However, from the reports received and the visit of personnel to Russia, it is known that active work at a reasonably high level of cost is underway.

Fusion power has not quite reached the stage comparable to the first demonstration of self-sustaining nuclear fission in December 1942. It required nine years to demonstrate the production of electricity from nuclear fission and now eight years later the economic potential of fission power plants still is not clear. Moreover, the neutron physics problems involved in nuclear fission were less formidable than are the physics problems of fusion, and the engineering technology needed for the transition to practical application of nuclear fission was in existence.

In the case of fusion power, the basic particle reactions are understood to a degree. However, no controlled means for attaining the required environment for these reactions exists. The methods of maintaining particle reactions in a controlled state are in their infancy. Moreover, the assumption that existing engineering methods can be applied to the fusion process may not be valid. The attainment of a technology capable of extracting power from fusion may take longer than the development of the means for attaining controlled fusion.

I - DIRECT CONVERSION

Three processes for the direct production of electricity from energy sources are described below as they relate to their potential application to nuclear power

Thermionic Generation. In this process,heat drives electrons from a material that freely emits electrons at elevated temperature. The electrons are collected by a cathode. On completion of the circuit, a current flows. The feasibility of this method for nuclear applications has been demonstrated at Los Alamos. The theoretical efficiency of this process is fairly high - certainly well above 50 per cent.

Thermoelectric Generation. In this process, two materials are connected at a heated junction and at a cooler junction. The differences in material properties and temperatures causes a current to flow. This principle is the basis of the familiar thermocouple. The principle has been applied successfully to produce electricity from the heat a of a decaying isotope in the SNAP device. The application to a central station power source is doubtful due to engineering difficulties. The efficiency of this process for nuclear heat is low - probably not greater than 10 per cent in the best case.

Magnetohydrodynamic Generation. In this process, an ionized plasma is caused to flow through a fixed magnetic field. The motion of the ionized particles in the magnetic field produces electromagnetic forces which separate the positive and negative charges. These charges are collected and produce a potential difference. If the engineering problems are solveable for a conventional heat source, then the process could be applied to nuclear power. The theoretical efficiency of the process is very high - over 85 per cent. However,practical consideration such as radiant heat loss limits the maximum attainable efficiency from 60 to 70 per cent.

Active research is underway on all of these approaches. There is insufficient information to assess their possible potential for central station use. There is no assurance that any can be successfully applied for large scale economic power production but one cannot rule out the possibility that one of these principles, or some other, may be developed for such application. The economics of direct conversion for central station use cannot be evaluated until practical machines can be designed and demonstrated. It is not possible to predict when this might be.

J - RESEARCH REQUIREMENTS

Potential improvements in nuclear plants leading to lower energy cost can be divided into two general areas: reduced plant investment costs and reduced fuel cycle costs. Much improvement in both areas will be evolutionary in nature, dependent primarily on operating experience and only partially attributable to "pre-operational" research. Other improvements depend heavily on research and development efforts.

The following major areas can be identified for the reduction of plant costs:

1 - Simplification of systems. This includes the reduction of shield thicknesses, omission of unnecessary instrumentation, elimination of valves, optimized plant layout, and the simplification of waste handling. These are mostly evolutionary and will result from experience either in operation of plants or in their design with very little pre-operational research.

2 - Development of Components. This includes, for example, control rod drives, pressure vessels, heat exchangers, pumps, valves and fuel element handling mechanisms. These involve design studies, testing and perhaps development of materials and fabricating techniques. In the conventional power plant industry, this type of development is normally conducted by equipment manufacturers and the development cost is included in their selling price. Because of the unique requirements of the nuclear industry, equipment development costs are likely to be high. Usually, components are designed or developed to meet known specifications and their development is associated with the construction of a particular plant. This would be particularly true for a relatively well developed concept, in which case the improvements would be largely evolutionary. For less developed concepts, satisfactory components may be unavailable, in which case design and testing may be carried out independently of plant construction plans or alternate designs may be developed to arrive at a suitable choice.

3 - Reduction of the cost of reactor containment and other safety measures. A significant item in the cost of certain reactor types, notably those cooled with water, is the reactor enclosure designed to prevent the escape of radioactivity in the event of a primary system rupture. Although more economical alternate schemes and structures have been considered as substitutes for the steel pressure shell type of full vapor containment, detailed analysis and some experimental work is necessary to determine their adequacy.

4 - Improvement of reactor thermal performance. This involves heat transfer, fluid dynamics, materials development and in-core instrumentation. In the case of the boiling reactor, it involves steam separation. Most improvements from such development results from "pre-operational" research. The objectives are, primarily, increased coolant exit temperature and higher power density. Improvement in thermal performance may be aimed at reduced fuel cycle costs as well as reduced plant costs. Development of improved reactor control is largely aimed at maximizing thermal performance and response to changing load demands although it may also be directed toward increasing fuel life through power flattening and control of excess reactivity resulting from increased fuel enrichment.

5 - Shortening of construction schedule. This would reduce indirect construction costs. Most of the savings in time of construction for a nuclear plant will result from shortening the design period for long delivery items such as the turbine-generator and reactor vessel. Such an improvement is mostly evolutionary.

Improvement in fuel cycle costs will result largely from the extension of fuel irradiation levels, reduction of fabrication costs and improvement in fuel utilization by better neutron economy. Specific areas include:

1 - Demonstration of high fuel irradiation level. Most types of fuel elements proposed for central station power reactor use are expected to attain higher irradiation levels in terms of maximum megawatt days per ton than have been demonstrated in actual performance for any reactor core. Of major importance from a development standpoint is the accumulation of actual performance data. From a practical standpoint, this can only be accomplished in operating power reactors. Although energy cost estimates for UO_2 fuel elements in AEC "current status" plants is predicated on attainment of a peak fuel exposure of 27,000 mwd/t, the only reactor operating experience with this type of fuel is with the Shippingport reactor which has accumulated only 8000 mwd/t maximum to date although examination indicates the elements are still in excellent condition. The average irradiation level of the Shippingport blanket is about 2000 mwd/t compared to 13,000 mwd/t assumed for a "current status" pressurized water reactor. Extension of the demonstrated fuel life will be mostly evolutionary, depending on examination of failed elements and correction of defects.

2 - Development of new fuel element types with higher burn-up potential. Currently available fuel elements for certain reactor types are so severely limited in fuel burn-up capability that economic considerations demand the development of alternate fuel materials or designs. Examples are the aluminum clad uranium alloy fuel elements used in the organic cooled reactor and uranium-10 per cent molybdenum elements used in the thermal and fast sodium cooled concepts. More promising elements are UO_2 elements clad in sintered aluminum alloy for the organic cooled reactor and uranium monocarbide (UC) for the sodium cooled reactors. Development of suitable manufacturing techniques are needed in both cases after which extensive testing in operating power reactors will be necessary to demonstrate actual performance.

3 - Improvement of maximum to average irradiation levels either through power flattening or fuel management. This involves a better understanding of reactor physics and reactivity transients as functions of fuel irradiation. It involves better understanding of heat transfer details. In addition to increasing the average irradiation level, improvement in power distribution may be reflected in higher average specific power and a consequent reduction in fuel inventory costs. This type of improvement requires substantial research effort.

4 - Reduction in fuel fabrication costs resulting from accumulated experience and increased volume of operations. Even though fuel designs and manufacturing techniques are not changed appreciably, the cost of fabricating subsequent cores can be expected to be lower than for the first core. This results from lower development costs as well as fewer rejections and lower scrap losses. Inspection techniques may be improved in effectiveness at reduced costs. Increased volume of production, particularly if designs are standardized, would result in increased savings. If the volume of production is large enough, mechanization and automation may result in greater savings. For a commercial operation for which the fuel fabricator provides a burn-up warranty, the satisfactory performance of previous fuel elements in actual operation should be reflected in lower fabrication prices and/or more favorable warranties. The actual reduction in cost will of course depend on the fabricator's practices in the distribution of development costs and in the amortization of plant and equipment. Cost improvements for repetitive fuel fabrication will be mostly evolutionary.

5 - Reduction in fuel element cost through development of new materials and fabrication techniques. Cheaper or more reliable fuel and cladding materials may be developed as well as cheaper methods of fabrication such as swaging. For the most part, these require considerable research and testing effort. After they have reached the applied stage, further improvement will be largely evolutionary.

From these considerations it would seem that maximum progress toward economic nuclear power from the currently more advanced reactor types, such as the light water reactors, will be achieved from operating experience with reactors under construction and research and development specifically aimed toward reactors planned for construction. Maximum progress for other types will be achieved by emphasizing research and development on components and critical areas with plant construction limited to reactor experiments and prototypes.

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(12) Atoms in Japan - Japan Atomic Industrial Forum. Vol 4, No. 1 January 1960

(13) Letter from C H Weaver to R McKinney March 29, 1960 (Reproduced in Appendix A to this report)

(14) Letter from R J Cordiner to R McKinney March 24, 1960. (Reproduced in Appendix A to this report)

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APPENDIX A

Correspondence Related to
Firm Price Proposals for Construction
of Nuclear Plants in the United States

LETTER DATED MARCH 29, 1960 FROM C. H. WEAVER, VICE PRESIDENT, WESTINGHOUSE ELECTRIC CORPORATION TO MR R. McKINNEY IN REPLY TO INQUIRY REGARDING OFFERS MADE TO CERTAIN CALIFORNIA UTILITIES

Westinghouse Electric Corporation
March 29, 1960

Mr. Robert McKinney
U. S. Atomic Energy Commission
1717 H Street, N. W.
Washington 25, D. C.

Dear Mr. McKinney:

The following information concerning the large atomic power plant which we have discussed with electric utility companies in the United States is submitted in reply to your letter of March 15 to Mr. Cresap. The numbered paragraphs refer to your specific questions.

1. The plant is a 360 megawatt gross electrical output nuclear power plant with a closed cycle light water cooled and moderated nuclear steam generator.

2. We have proposed a fixed price of $68,000,000 subject to normal escalation and exclusive of necessary research and development costs. The price includes a nuclear power plant on a normal site complete up to the high voltage terminals of the main transformer, ready for commercial operation. It does not include the nuclear fuel. Further, the utility must provide the site, a railroad siding into the site, administration of the contract, obtaining of all licenses - state and Federal, preparation and presentation of hazards reports with the assistance of the contractors, training of operating personnel with Westinghouse assistance, and interest on the money required during construction.

3. As indicated above, the price of the plant is fixed subject to normal escalation. Westinghouse warrants the 360 MW gross output rating of power plant and an average fuel burn-up of 14,700 megawatt days per long ton on the equilibrium fuel cycle.

4. Energy production cost estimates for power plants are the responsibility of the utility. However, we have made certain assumptions and on this basis estimate the cost of net energy produced by the plant as 7.3 mills per kilowatt hour. The assumptions used in the preparation of this estimate are:

   a. 30 MW auxiliary load or a plant net electrical output of 330 MW.

   b. Annual charges of 12-1/2%.

c. Load factor of 90%.

d. Plutonium credit of $12 per gram.

e. Today's prices for plant, uranium, fuel use charge, core fabrication, reprocessing, transportation and other services.

The Cost elements are:

	Mills/KWH
Capital cost based on $68,000,000	3.3
Utility costs capitalized at $10,400,000	.5
Operation, Maintenance and Nuclear Insurance	.5
Fuel costs (equilibrium core)	3.0
Total	7.3

5. The site was selected as one in Zone 1. The plant can be readily adapted to other sites less favorable from the earthquake standpoint.

6. We have not as yet made any proposals covering the 360 MW gross plant outside the United States. Factors which might modify such proposals in Western Europe include the different voltage and frequency which tend to decrease the plant capability and increase the cost of the components, local site considerations and labor costs. Overall, we would not expect the resultant power cost to be substantially different from that estimated for the United States.

Sincerely,

Charles H. Weaver
Vice President

CHW:ns

LETTER DATED MARCH 24, 1960 FROM R. J. CORDINER, CHAIRMAN OF THE BOARD GENERAL ELECTRIC COMPANY TO MR. R. McKINNEY, IN REPLY TO INQUIRY REGARDING OFFERS MADE TO CERTAIN CALIFORNIA UTILITIES

General Electric Company
March 24, 1960

Mr. Robert McKinney
Congress of the United States
Joint Committee on Atomic Energy
Washington, D. C.

Dear Mr. McKinney:

I am glad to be of service to you in your review of the costs of atomic power plant construction and operation by supplying you information regarding our recent proposals to the United States and foreign utilities.

You will understand that this information must be somewhat generalized and that it would be inappropriate for us to disclose the details of our communications with prospective customers. In this light, we trust that the following information will be fully adequate for your purpose.

1. General Electric has offered for sale boiling water atomic reactor power plants in the 200 and 300 MW range.

2. These proposals are on a fixed price basis, including provision for escalation. We have quoted both as a prime contractor and also as a sub-contractor to the utility involved, or at his request, to a qualified engineering firm, for the nuclear steam supply system, including the technical management of the project. The costs for the complete plants, excluding the land and interest charges during construction, approximate $230 per KW for the 200 MW plant and $210 per KW for the 300 MW plant.

3. We will warrant 10,000 to 15,000 MWD/ton fuel burn-up and quote fixed prices with escalation on fuel fabrication. Burn up and fabrication costs vary and depend upon the enrichment and cladding.

4. The total energy production costs will vary, depending upon the particular utility's situation in taking account of fixed charges and load factor. These are calculated by the utility, but our information is that the costs range from 7.5 to 10 mils per KWH. All the cost elements normally taken into account by the utilities are included.

5. The plants which we are quoting meet standard local codes for earthquake protection. The costs also include provision for adequate safeguards based upon our experience to date.

6. We are now making proposals on plants outside of the United States in sizes up to 200 MWs. It is difficult to generalize with regard to costs of foreign plants, particularly where much of the material may be of foreign procurement and construction. The location of the particular plant is particularly significant in this connection. In Western Europe, however, our observation is that the overall effect is to result in a slightly lower cost than we would anticipate here.

I hope that the foregoing serves your purpose; but if your studies develop need for other information, you can be assured of our willingness to attempt to secure it for you.

Sincerely yours,

Ralph J. Cordiner

RJC:ns

LETTER DATED MARCH 24 1960 FROM N R SUTHERLAND, PRESIDENT PACIFIC GAS AND ELECTRIC COMPANY TO MR R McKINNEY

March 24 1960

Mr Robert McKinney
c/o U S Atomic Energy Commission
Room 1151
1717 H Street, N W
Washington 25, D C

Dear Mr McKinney:

Mr Black has asked me to reply to your letter of March 15, 1960, in which you request certain data from us concerning recent reactor construction proposals which have been submitted to the Pacific Gas and Electric Company.

We are now studying pressurized water and boiling water nuclear power plants in sizes between 300 and 360 MW electrical output. All of the information, however, has not been received, and until then our studies cannot be completed.

Your letter seems to indicate that you are under the impression that we have arrived at a decision on the proposals which have been submitted. Since this is not the case, I am sure you understand why we are not in a position to answer many of your questions. I believe most of the information you seek now could be obtained from the manufacturers since one of them has published considerable detail on their 360 MW pressurized water job.

In connection with the present studies, we have found that the manufacturers are willing to bid directly on their equipment on a fixed price basis or with an architect engineering firm on the complete plant, exclusive of land. Fuel warranties are better than when Humboldt was purchased. I believe considerable progress is being made in lowering the cost of nuclear power, and I am glad to know of your continued interest in the subject.

Yours very truly,

/s/ N R Sutherland
President

NRS:ACS

LETTER DATED MARCH 22 1960 FROM J K HORTON, PRESIDENT SOUTHERN CALIFORNIA EDISON COMPANY TO MR R McKINNEY

March 22 1960

Mr Robert McKinney
c/o U S Atomic Energy Commission
Room 1151
1717 "H" Street, N W
Washington 25, D C

Dear Mr McKinney:

Although we have received proposals from nuclear equipment manufacturers and an architect-engineer for the 340 MW atomic power plant, we would be reluctant to disclose the terms of the proposal at this time. We are still discussing the proposals with the manufacturers and believe it would be most difficult to answer specific questions because of the current status of negotiations. We are now investigating the economic feasibility of the project and have not made a decision for further action with respect to these negotiations.

Sincerely yours,

/s/ J K Horton
President

JKH:hm

APPENDIX B

EURATOM POWER COST ESTIMATES

from the report

A Target for Euratom

by the

"Three Wise Men"

May 1957

ESTIMATED COST OF ELECTRICITY

(in mills per kilowatt-hour)

	PWR	BWR	PIPPA
Fuel costs:			
Uranium in fresh fuel[a]	5.8	2.1	2.0
Fuel fabrication[b]	1.1	1.7	0.4
Chemical reprocessing[c]	0.4	0.3	0.3
Plutonium credit[d]	-0.9	-0.8	-1.0
Uranium credit[e]	-3.7	(-0.3)	(-0.3)
Net fuel cost	2.7[f]	3.3[f]	1.7
Other operating costs[g]	1.0	1.0	1.0
Fuel inventory charges[h]	1.3[f]	0.8[f]	0.7
Capital charges[i]	6.3	5.4	7.4
Total cost of electricity	11.3	10.5	10.8
Total plus 25% contingency[j]	14.1	13.1	13.6
COST RANGE	11.3-14.1	10.5-13.1	10.8-13.6

Notes:

(a) Uranium costs in fresh fuel are based on the schedule of charges for enriched material announced by the U.S. A.E.C. on the 18th November, 1956, and on the price for natural uranium metal of $40/kg announced 8th August, 1955.

(b) Fabrication costs for PWR stainless steel elements $60/kg U, and for BWR zirconium elements $115/kg U, including the cost of conversion of UF_6 to UO_2 and scrap recovery, and allowing all operating and overhead charges for fuel fabrication plant on a production basis. In the case of PIPPA, a charge of $9/kg is allowed for fabrication from metal, being the difference between the price of £17,500/tonne for fuel elements quoted by the U.K. A.E.A. and the cost of the uranium at $40/kg. The price of £20,000/tonne often quoted in this connection is the U.K. A.E.A.'s estimate of a long-term maximum value, including allowance for possible increases in the cost of uranium metal and of improved canning materials and the fabrication of fuel elements.

(c) The cost of recovery from PWR and BWR irradiated fuel of plutonium and uranium in the form of nitrate is based on the charge of $15,300/day announced by the U.S. A.E.C. on 18th February, 1957 for a 1 ton/day plant. These charges assume a plant capacity of 300 tonnes/year and include waste disposal, but not transport (shipment to the U.S. for processing would cost about 0.2 mills/kWh). In the case of PIPPA the U.K. A.E.A. estimate of £2,500/tonne for a plant to process 2,000 tonnes/year of Magnose-clad elements is assumed.

(Notes continued to following page.)

5. The many variables which must be adopted in such calculations of nuclear power costs are often lost sight of, leaving only the final figure in mind. To guard against this danger, a contingency of 25% has been added to the above estimates of costs below, which have been calculated on the basis of what appears to be reasonably achievable as average costs during the life of plants brought into service early in the 1960's and the costs then shown as a range. This contingency serves to emphasize the actual uncertainties inherent in cost estimates made at this time, and it may be interpreted to include all adverse elements which might combine to raise costs. For example, the 25% figure allowed would cover at the same time a rise of 50% on operation, 25% on fabrication and processing, 15% on plant investment (and insurance) and a reduction of irradiation by 25%, all together. These factors are unlikely all to go in the unfavorable direction, particularly in view of improvements in fuel cycle costs.

(Notes continued from preceding page.)

(d) The plutonium recovered from PWR and BWR fuel elements is credited at the price of $12/gm for metal announced by the U.S. A.E.C. on 18th November, 1956, less the official charge of $1.50/gm for conversion of nitrate to metal. For PIPPA the U.K. A.E.A. value of £5,000/tonne plus £2,500/tonne for reprocessing is assumed; this gives $11.70/gm for nitrate.

(e) The uranium recovered is credited according to the U.S. A.E.C. schedule announced 18th November, 1955 in the case of PWR. The bracketed credits for BWR and PIPPA are not allowed in the net fuel cost, because they are calculated by linear extra-polation of the published schedule below natural uranium concentration. In all cases, an estimated charge of $3/kg U for conversion from nitrate to UF_6 is deducted.

(f) This difference of fuel costs and inventory charges is a consequence of fuel element design, not of differences between the two reactor types.

(g) Operating costs assume $7/kW-year for operation, maintenance and stores in all cases, giving 1.0 mills/kWh at 80% load factor.

(h) Fuel inventory is charged at 8% on the actual value of the fuel throughout its cycle, including fabrication, transport, storage, in pile, cooling, transport and processing.

(i) Capital charges of 13% are assumed as an average representative of conditions in the six countries, covering interest and depreciation (over 15 years) and overheads, but excluding taxes and special nuclear risk insurance. (Provisional U.S. domestic rates for special nuclear insurance would come to about 0.2 mills/kWh, subject to revision based on experience at the end of ten years).

(j) For contingency, see para. 5 above.

APPENDIX C

U S EURATOM WORKING PARTY -

WORKING PAPERS

Working Paper III
Estimated Conventional and Nuclear
Power Costs in Euratom Countries

Working Paper IV
Fuel Cycle

Working Paper XII
Sale of Nuclear Fuel

U. S. - EURATOM WORKING PARTY

WORKING PAPER III

ESTIMATED CONVENTIONAL AND NUCLEAR
POWER COSTS IN EURATOM COUNTRIES

In the following tables, conventional power costs have been estimated on the basis of a level of prices for coal and fuel oil imported by EURATOM countries that can be normally expected.x) Nuclear power costs have been estimated for 1963, when the reactors in the 1,000,000-kilowatt U.S.-EURATOM program are expected to go into operation. The fuel-cycle cost for these reactors is expected to decrease as time goes on.

Various cases have been considered in order to cover the range of present possibilities in Europe.

Cases A and B are for new, conventional power plants. Case A is for imported coal and case B for imported fuel oil.

Cases C, D and E are for nuclear power plants of the pressurized water type having construction costs per electrical kilowatt of $300, $250, and $350, respectively. It has been assumed that one half of the construction cost is financed in Europe at an interest rate of 8% per annum and for purposes of calculation it has been assumed that one-half is covered by a U.S. Government loan at an interest rate of 4% per annum, so that the average is 6%. Interest during construction is taken at the 8% rate (amounting to a total of 16% over the construction period).

For cases A through E, an amortization period of 15 years is assumed.

Cases F and G are for conventional and nuclear power plants, respectively, and assume government financing at an interest rate 4.75% per annum and amortization over a period of 30 years.

x) It is to be noted that, due to current freight rates, these prices are presently lower.

CALCULATION OF FIXED CHARGES

		A Coal	B Fuel Oil	C Nuclear	D Nuclear	E Nuclear	F Coal	G Nuclear
Basic Assumptions								
Net Electric Power	Megawatts	150	150	150	150	150	150	150
Construction Cost	$/kw(elec.)	135	110	300	250	350	145	300
Interest Rate	%/year	8	8	6	6	6	4.75	4.75
Interest during Construction	Total, %	16	16	16	16	16	9.5	9.5
Amortization Period	Years	15	15	15	15	15	30	30
Amortization Rate*	%/year	11.7	11.7	10.3	10.3	10.3	6.3	6.3
Taxes and Insurance	%/year	2	2	3	3	3	-	1
Load Factor	%	80	80	80	80	80	80	80
Calculations								
Plant Investment**	$/kw(elec.)	160	125	348	290	405	160	328
Total Fixed Charges	%/year	13.7	13.7	13.3	13.3	13.3	6.3	7.3
Total Fixed Charges	Mills/kwh	3.1	2.5	6.6	5.5	7.7	1.5	3.4

* Equal annual payments to cover principal and interest.

** Construction cost plus interest during construction.

ESTIMATION OF FUEL COSTS

CONVENTIONAL FUELS x)

Conventional Fuel	Energy Content (kilocalories/kg)	Dollars per Metric Ton	Mills per Kilowatt Hour
Imported Coal	6,800	18.50	6.8
Fuel Oil	9.700	24.50	6.3

+ Assumes 2,500 kilocalories per kilowatt hour.

NUCLEAR FUEL

Assumptions:

1. Type of nuclear power plant taken into consideration: PWR or BWR 150 EMW using uranium with an enrichment lower or equal to 3%, similar to power plants already constructed or in the course of construction in the U.S.A. The following calculations are based on the case of a PWR.

2. The inventory costs have been computed on the basis of a 4% interest rate on the initial value of the enriched uranium supplied for the inventory, assumed to be one full loading of the reactor plus one and a half times the annual throughput, in order to take into account fuel elements in storage, in the course of transportation, cooling or reprocessing.

3. An average guaranteed irradiation level of 10,000 MWD/metric ton of uranium and a fabrication price of $100/kg (stainless steel cladding) have been considered for the fuel elements. This price includes all costs starting with uranium hexafluoride furnished by the U. S. A.E.C. to the manufacturer up to the finished element, packed FOB fabrication plant, thus including previous transportation, all manufacturing and supplies, namely cladding metals, and all other expenses. The price does not include the U. S. A.E.C. charge for enriched uranium.

4. Processing and conversion charges for irradiated fuel have been based on the following papers:

"AEC Offers Processing Service to Owners of Private Reactors"
No.983 of February 18, 1957

"AEC Notice Outlines Basis for Chemical Processing Contracts"
No.999 of March 7, 1957

"AEC Specifies Conversion Charges Relating to Chemical Processing Service"
No. A-47 of March 12, 1958

x) See footnote page 1.

5. The enriched uranium purchase price was computed on the basis of document "Schedule of Charges", published by the U. S. A.E.C. on November 18, 1956.

6. Plutonium has been credited at the U.S. published fuel value of $12 per gram of metal less the U.S. published charge of $1.50 per gram for converting plutonium nitrate to plutonium metal, including losses. Under these conditions, the fuel cycle costs in mills per kwh are:

Fuel inventory	0.6	Mills/kwh
U-235 burn-up	2.3	
Fabrication	1.5	
Chemical processing	0.3	
Conversion of UNH to UF_6	0.1	
Transport and insurance	0.3	
Plutonium credit	-0.9	
Total Mills/kwh	4.2	

It should be noted that these costs are necessarily approximate and should be reviewed in detail for each particular project and even for each new core loading. However, it is the opinion of the Joint U.S. Euratom Working Party that, on the basis of the stated assumptions, the calculations provide reasonable estimates of the initial fuel-cycle costs under this program.

TOTAL COSTS OF POWER IN MILLS

PER KILOWATT HOUR

	A Coal	B Fuel Oil	C Nuclear	D Nuclear	E Nuclear	F Coal	G Nuclear
Fixed Charges	3.1	2.5	6.6	5.5	7.7	1.5	3.4
Fuel Cycle Costs	6.8	-6.3	4.2	4.2	4.2	6.8	4.2
Operation & Maintenance	1.0	1.0	2.0	2.0	2.0	1.0	2.0
Total	10.9	9.8	12.8	11.7	13.9	9.3	9.6

U S - EURATOM WORKING PARTY

WORKING PAPER IV

FUEL CYCLE

A. OBJECTIVE

The objective of the fuel cycle program is that arrangements for supplying fuel elements for the million kilowatt cooperative program will meet either criterion (1) or (2) below:

(1) The integrity of the stainless steel or zirconium clad fuel elements for light-water cooled and moderated reactors is guaranteed to an average irradiation level[1] of 10,000 megawatt days per metric ton of contained uranium[2]; and the charge[3] for fabrication of fuel elements starting with uranium hexafluoride is:

(a) $100 per kilogram of contained uranium for fuel elements made of uranium dioxide having a U-235 isotopic concentration no greater than 3% by weight, diameter between 0.25 and 0.50 inches, and stainless steel cladding; or

(b) $140 per kilogram of contained uranium for similar fuel elements clad with zirconium cladding; or

(c) appropriately adjusted charges for fuel elements having different claddings or falling outside of the limitations on size, shape, or U-235 concentration.

Note: For each type of fuel element, there will be computed as mutually agreed, "computed fuel cycle costs" based on guaranteed average irradiation levels and fabrication charges, and taking into account all charges for fuel fabrication, inventory, burnup, chemical reprocessing, and transportation and the credit for plutonium. If the fabrication level and fabrication charge used in this computation are those given in A (1), the computed fuel cycle cost is defined as the "standard fuel cycle cost".

(2) The irradiation level in the integrity guarantee and the fabrication charge for fuel elements differ from the values specified in (1), but the combination gives a computed fuel-cycle cost equal to or less than the standard fuel cycle cost.

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1. Average irradiation level will be based on a weight of fuel equivalent to the nominal fuel loading of the reactor.

2. Adjustments of the integrity guarantee may be required if cladding materials other than stainless steel or zirconium are used.

3. Fabrication charges will be subject to escalation on the basis of a mutually determined index.

B. GUARANTEES

1. Arrangements for supplying fuel elements that meet criterion (1) or (2) may be received from commercial sources but, in the event of failure of fuel elements, such arrangements may not sufficiently cover the extra costs of reprocessing and transporting irradiated fuel elements to meet the standard fuel-cycle cost. Under such conditions, the United States Commission will, for the purposes of prorating the chemical processing and/or transportation costs, offer to guarantee an average irradiation level, which, in combination with the guarantees offered by the manufacturer, would result in a computed fuel-cycle cost equal to the standard fuel-cycle cost. When such guarantees are made, if the average irradiation level actually attained is greater than the irradiation level guaranteed by the United States Commission, one-half of the resulting savings in costs of reprocessing and/or transporting irradiated fuel will be credited to the United States Commission, up to the sum of previous payments by the United States under this guarantee for the particular reactor concerned.

2. In the event that acceptable arrangements for supplying fuel elements meeting the criteria of A above are not received from commercial sources, the United States Commission will guarantee the fuel elements supplied under the following arrangements:

(a) If the fabrication charge guaranteed by the manufacturer is equal to or less than the value specified in A (1) above, the United States Commission will guarantee an average irradiation level which, when combined with this fabrication charge, will give a computed fuel-cycle cost equal to the standard fuel cycle cost.

(b) If the average irradiation level guaranteed by the manufacturer is equal to or greater than the value specified in A (1) above, the United States Commission will guarantee a fabrication charge which, when combined with the average irradiation level in the manufacturer's integrity guarantee, will give a computed fuel-cycle cost equal to the standard fuel-cycle cost.

(c) If the average irradiation level is less and the fabrication charge is greater in the manufacturer's guarantee than in A (1) above, the United States Commission will offer to guarantee the values in A (1).

In cases (b) and (c) above, when the average irradiation level attained exceeds that guaranteed by the United States Commission, one-half of the resulting savings in fabrication costs will be credited to the United States Commission, up to the cost of payments by the United States Commission for fabrication charges for the particular core concerned.

If the average irradiation level does not meet that guaranteed in (a), (b), or (c) above, the United States Commission will adjust the charges for fabrication, chemical reprocessing, and transportation to the level that would have been incurred had that guarantee been met.

3. Fuel-element guarantees may also be developed for proven types of reactors other than light-water cooled and moderated, determined by the Euratom Commission and the United States Commission to be eligible for consideration under the joint program.

4. The guarantees provided by the United States Commission under paragraphs 1, 2, or 3 of this section will be applicable to all loadings made in the reactor during ten years of operation or prior to December 31, 1973, whichever is earlier.

5. In determining whether a guaranteed average irradiation level has been attained, account will be taken not only of all material discharged because of actual failure of integrity, but also material whose discharge, in the joint opinion of the Euratom Commission, the United States Commission, and the fabricator involved, was required for purposes of safe operation or economic operation (assuming for the latter determination that no guarantees were in force).

6. The technical and economic criteria under which proposals will be evaluated for acceptance will include minimum standards for fabrication charge and integrity guarantee for fuel elements. These criteria will also provide, as may be agreed, that subsequent reactor cores can be furnished by other than the initial fabricators.

7. In order to qualify for the guarantees by the United States Commission provided in paragraphs 1, 2, and 3 of this section, fuel elements must be fabricated by a United States manufacturer or by a manufacturer in Euratom countries under agreement with a United States firm or firms. However, reactors under the joint program may be fueled with elements from other sources. In such cases, the United States Commission will offer to perform chemical reprocessing services at its published charges with respect to any source or special nuclear material obtained from the United States. If adequate facilities are not available in Euratom when needed, the United States Commission will give sympathetic consideration to furnishing reprocessing services on material not furnished by the United States Commission.

8. The United States Commission guarantees will, in general, be extended to the utility through the fabricator of the fuel. In the event that it is determined by the United States Commission that the fabricator is not meeting adequate performance standards, or, if it is mutually determined that a more advantageous source is available, other contractual arrangements will be made for supplying fuel elements under the guarantee.

U S - EURATOM WORKING PARTY

WORKING PAPER XII

SALE OF NUCLEAR FUEL

The fuel inventory for a nuclear power program consists of fuel in the reactors, fuel being prepared for insertion in the reactors, fuel being processed after discharge from the reactors, and fuel in storage or transit. It is estimated that the initial U-235 content of the fuel inventory supplied for the 1,000,000 kilowatt program will be approximately 9,000 kilograms in the steady state, but this will depend on the reactor designs, U-235 isotopic concentrations used, irradiation levels achieved, and other factors and will be determined jointly. By agreement between the United States and Euratom, adjustments will be made in the amount of material assigned to the fuel inventory to take account of changes in technology.

The United States will sell to Euratom the enriched uranium in that portion of the fuel inventory transferred to Euratom, at U S domestic prices in effect at the time of the transfer. Payment by Euratom on the principal may be deferred for a period not to extend beyond December 31, 1973, with interest to be paid by Euratom on this debt at a rate of 4% per annum. After the deferral period, Euratom will start paying in equal annual installments, the debt incurred for the fuel inventory, plus interest at 4% per annum on the unpaid balance. These payments will be completed during a period not to extend beyond December 31, 1983.

Enriched uranium transferred to Euratom above the amount of the agreed fuel inventory will be paid for by Euratom at the time of the transfer, at U S domestic prices in effect at that time. Uranium returned by Euratom to the United States will be paid for by the United States at the time of the return, at U S domestic prices in effect at that time.

Plutonium acquired by the United States from Euratom will be used only for peaceful purposes. To assure this, in any case where such material cannot, during its reprocessing, be kept separate from plutonium produced in the United States, an equal amount of U S plutonium will be reserved for peaceful uses. Plutonium purchased from Euratom by the United States will be paid for at the U S announced fuel-value price in effect at the time of the purchase.

LETTER OF REQUEST TO ATOMIC ENERGY COMMISSION

This will confirm our discussion * * * concerning the preparation by the Commission of a report in two parts on the status and prospects for atomic power.

While we have not yet had an opportunity to see the entire 10-year program report of the Commission, it would appear likely that all or most of the work necessary for the report requested herein has recently been completed by the Commission in this undertaking.

The review staff will, of course, be available to discuss the detailed characteristics of the requested report and its substance and format should you so desire.

TRANSMITTAL LETTER FROM ATOMIC ENERGY COMMISSION

* * * you requested a report on the Status and Prospects for Atomic Power.

* * * * * * *

Enclosed you will find * * * a summary prepared by the Commission's Division of Reactor Development "Current Status and Potential of Various Concepts of Nuclear Reactors for Use in Central-Station Generation of Electricity." * * *

* * * * * * *

CURRENT STATUS AND POTENTIAL OF VARIOUS CONCEPTS OF NUCLEAR REACTORS FOR USE IN CENTRAL-STATION GENERATION OF ELECTRICITY

The AEC, in its recently published report, Summary of Technical and Economic Status as of 1959, evaluated the accomplishments in the development of nuclear power reactors, both in the United States and abroad. In addition, the report Economic Potential and Development Program analyzes the potential of the various concepts and outlines the scope and cost of the development and construction program necessary to achieve the potential and the time when it could be realized. A summary of those reports follows.

Only those concepts were considered which have sufficient technical bases to allow today the assumption of technical feasibility; development programs were projected only to the extent that it is reasonable, on the basis of present knowledge, to foresee success. Aside from nuclear superheat, no major modification of concepts as now known was assumed.

For example, it was not attempted to introduce into the studies the effect of variable moderation or spectral shift on the potential of the water concept, nor the long range effects of programs such as Turret or Pebble Bed on the gas-cooled concept; the analysis of the

fast reactor systems did not attempt to give weight to the potential impact of the Los Alamos Molten Plutonium Reactor Experiment. No attempt was made to study the potential of other moderators such as graphite or D_2O when used with organic coolants; the use of graphite moderation in water systems was not analyzed; no attempt was made to determine the potential of epithermal reactor systems; the possibility of open or closed cycle gas turbine systems was not evaluated. Furthermore, it was not assumed that current charges for reprocessing and transportation would be decreased, that waste disposal techniques would be improved, or that there would be major cost reductions as a result of high volume throughput in fuel fabrication.

The principal assumptions made in carrying out the studies reported were:

1. All research and development and engineering test programs would be successful.
2. A load factor of 80 percent would be experienced.
3. Current estimates of construction time, engineering costs, and component costs, were assumed to remain in effect.
4. All economics were based on a one reactor, one turbine station.
5. It was assumed that operating, maintenance, and insurance costs would remain high for nuclear plants.
6. No increase in reactor capacity beyond design power was assumed.
7. No decrease in the cost of Uranium 235 was assumed.

In the case of each concept considered, the cost of power from a 300 electrical megawatt plant that could be built with today's technology without major extrapolation, the areas where we have assumed cost reductions could be made, the extent of such potential reductions and hence the cost of power from the "potential plant," the cost of the additional research and development program which would be required to achieve the reduction and the date when construction could be initiated on the "potential plant" were estimated. All cost data were based on an assumed 80 percent load factor, fixed charges at 14 percent, and plutonium value at $12 per gram.

PRESSURIZED WATER SYSTEMS

In this country, this system is at present the most technologically advanced as a result of the experience which has been gained in design and operation of the naval propulsion reactors, the Shippingport reactor, and the Fort Belvoir reactor, in the design and construction of such units as the NS Savannah, the Yankee Atomic Electric Co. Reactor, SELNI, Belgian Reactor No. 3, the Saxton Nuclear Experimental Reactor of the Nuclear Experimental Corp., Saxton, Pa., and the various Army reactors, and in the design studies on the small power and process heat reactors. The power costs from a 300 electrical megawatt pressurized water reactor that could be built with 1959 technology, namely 9.28 mills per kilowatt-hour, were found to be lower than from any other type of reactor. This cost consists of 5.05 mills for capital cost, 3.38 mills for fuel cycle cost, and 0.85 mills for operation, maintenance, and insurance.

Studies indicate that the substitution of primary pumps employing mechanical shaft seals rather than canned rotors, the elimination of external pressurizers, the modifications of the vapor containment, the use of bulk boiling, and the simplification and improvement of control drive mechanisms would allow a reduction in the total capital cost of the plant by 0.65 mills per kilowatt-hour, which makes that cost component for the "potential plant" 4.40 mills per kilowatt-hour.

More extensive reductions are indicated in the fuel cycle costs for this system. The fuel exposure for the uranium dioxide fuel can probably be increased from the 27,500 megawatt-days per ton maximum which is current technology to 40,000 megawatt-days per ton. It was also indicated that fabrication costs of stainless steel clad uranium dioxide can be reduced from the "current" level of $110 per kilogram of uranium to $70 per kilogram. These two factors would result in a total reduction in the fuel cycle cost of 0.82 mill per kilowatt-hour, making this factor in the "potential plant" 2.56 mills per kilowatt-hour.

It was assumed that the operating, maintenance, and insurance charges would remain at the 0.85 mill per kilowatt-hour level. The total cost for the power from the "potential plant" in the pressurized water system is thus 7.81 mills per kilowatt-hour.

In order to achieve the gains indicated above, a research and development effort of the order of $20,000,000 will be required between 1959 and 1965. It was concluded that by proper utilization of existing or soon to be existing plants, it would not be necessary to construct more experimental or prototype reactors over and above those now in operation, under consideration, or planned, and that a project aimed at construction of the "potential plant" could be initiated, concurrently with the research and development program, in the near future.

BOILING WATER SYSTEMS

This system is today only slightly less technologically advanced than the pressurized water system. This is due in part, of course, to the fact that it is able to take advantage of much of the extensive experience and technology developed in the pressurized water system. It is also due to the highly successful operating experience of the Experimental Boiling Water Reactor, the Vallecitos Boiling Water Reactor, and BORAX experiments, to the engineering experience that has been gained through design and construction activities of Dresden, Elk River, Northern States, Army reactors, etc., and through the design efforts on such units as the SENN (Societa Elettronuclear Nazionale) Punta Fiume Plant, the Humboldt Bay project of the Pacific Gas & Electric Co., and others.

It was estimated that a 300 electric megawatt dual cycle plant could be built on the basis of 1959 technology to produce power at a total cost of 9.61 mills per kilowatt-hour. This figure is made up of 5.26 mills for fixed charges, 3.47 mills for fuel cycle, and 0.88 mill for operation, maintenance, and insurance.

The capital costs factor of this system could be reduced by simplification of design to eliminate large risers and heat exchangers, by increasing the power density from 28 kilowatts per litre to 50 kilowatts per litre of core, and, by changes in the vapor containment

design. The total potential reduction in the capital costs by these changes is 0.95 mills per kilowatt-hour, bringing that component of the "potential plant" to 4.31 mills per kilowatt-hour.

The reduction in the fuel cycle costs would be brought about by the power flattening which is made possible by high power density elements, by increasing the average irradiation of the fuel to 19,000 megawatt-days per ton, and by reducing the fabrication costs for the Zirconium clad uranium dioxide from $140 to $90 per kilogram of uranium. The total potential reduction of the fuel cycle costs which can be brought about by these gains is 1.18 mills per kilowatt-hour, making this part of the power cost of the "potential plant" to 2.29 mills per kilowatt-hour. Again, operation, maintenance, and insurance were assumed to remain constant at 0.88 mills per kilowatt-hour and the total cost of power from the "potential plant" would be 7.48 mills per kilowatt-hour.

In order to achieve these gains, a development program amounting to approximately $20,000,000 was estimated to be necessary to be undertaken in the five-year period ending in 1965. In addition, it will be necessary to construct and operate a high power density prototype which will require an additional $25,000,000. Construction of the 300 electrical megawatt "potential plant" could start in late 1964 or early 1965.

NUCLEAR SUPERHEAT

While it was not believed possible to build an economic nuclear superheat reactor solely on the basis of 1959 technology, this concept offers a fair potential for reducing the cost of power from water reactors—either pressurized or boiling systems. In the studies, it was concluded that the cost of electricity from a 300 electrical megawatt water plant would be reduced by 0.73 mill per kilowatt-hour through the use of an integral nuclear superheat system. The cost reduction (0.43 mill for capital cost and 0.30 mill for fuel cycle) is due primarily to higher plant efficiency and reduction in turbine costs which is made possible by superheated steam. If these reductions are applied to the "potential plant" in the boiling system, a power cost of 6.75 mills per kilowatt-hour results.

In order to achieve the potential benefits of nuclear superheat, a development program, in addition to others discussed previously under water systems, of the order of $4,000,000 would be necessary to be carried out between 1959 and 1965 and a nuclear superheat prototype reactor would be required to be built and operated at a cost of approximately $20,000,000 during that period. A 300 electrical megawatt "potential plant" incorporating nuclear superheat could be under construction in 1965.

ORGANIC COOLED AND MODERATED SYSTEMS

In this system, the state of knowledge was found to be not as extensive as in the water systems. As a result, the cost of power from a 300 electrical megawatt plant built on 1959 technology would be 11.45 mills per kilowatt-hour. This figure is made up of capital costs of 4.39 mills, fuel cycle costs of 5.72 mills, and operation, maintenance and insurance costs of 1.34 mills. The lower capital cost for this

system, made possible because of its low pressure, noncorrosive aspects, is more than offset by the high fuel cycle costs resulting from the low exposure which can be achieved in the metal cores of current technology and by the high operating costs which are occasioned by the necessity for replacing the organic material as it is destroyed by reactor irradiation.

The potential of this system lies in the development of a new fuel element and cladding material which can achieve much longer life, in increasing the power density from 19 to 44 kilowatts per litre of core, and in increasing the heat transfer capabilities of the system. Studies indicate that the necessary results can be achieved and that the costs of power from the 300 electrical megawatt "potential plant" would be 6.67 mills per kilowatt hour, of which 3.53 mills are due to capital costs, 1.83 mills to fuel cycle costs and 1.31 mills to operation, maintenance and insurance.

In order to achieve these results, it would be necessary to undertake a research and development program amounting to approximately $40,000,000 between 1959 and 1965. In addition, $30,000,000 is needed for the construction and initial operation of a 75 electrical megawatt prototype reactor. Construction of the 300 electrical megawatt "potential plant" could be initiated in 1965.

SODIUM GRAPHITE SYSTEM

The operating experience of the Sodium Reactor Experiment, together with the experience of the naval reactors and the fast reactors programs, has indicated that it is technically feasible to use the sodium graphite system to produce power. Power costs from a 300 electrical megawatt plant based on current technology were estimated to be 11.22 mills per kilowatt-hour, of which 6.11 mills are for capital costs, 4.12 mills for fuel cycle and 0.99 mill for operation, maintenance and insurance.

In order to realize the potential of this system, it would be necessary to develop a new fuel material—the uranium-molybdenum elements on which current technology is based offer very little potential for reduction in fuel cost. However, by developing uranium carbide as a core material, by achieving a core life of 17,000 megawatt-days per ton, and by lowering fabrication cost for stainless steel clad uranium carbide elements to $70 per kilogram of uranium, the fuel cycle costs for this system would be reduced to 1.92 mills per kilowatt-hour.

In addition, by developing simplified and much less expensive steam generators, by confining the primary cooling system to the reactor vessel, by eliminating moving parts in the sodium stream, and by developing a calandria core to supersede the canned moderator core of current technology, it will be possible to reduce the capital costs of the plant by 1.19 mills per kilowatt-hour. It is also expected that increased knowledge of sodium handling systems will allow operating costs to be reduced by 0.05 mill per kilowatt-hour.

Taking into consideration all reductions which can reasonably be expected to be achieved, the cost of power from the 300 electrical megawatt "potential plant" will be 7.37 mills per kilowatt-hour of which 4.47 mills will be for capital costs, 2.00 mills for fuel cycle and 0.90 mill for operation, maintenance and insurance.

To accomplish this program, a development program, including the operation of the Hallam Nuclear Power Facility and the Sodium Reactor Experiment, of the order of $82,000,000 will be required between 1959 and 1967. In addition $50,000,000 will be required for construction of a 75 electrical megawatt prototype reactor. Such a program would make it possible to start construction of the 300 electrical megawatt "potential plant" by 1965 or early 1966.

GAS-COOLED REACTOR SYSTEMS

Gas-cooled technology in this country is not in a highly advanced position, since it is only quite recently that work in this field has become an important factor in the overall program. In spite of the fact that no gas cooled power reactors have been built or are even in an advanced state of design in this country, British experience on natural uranium gas cooled reactors, plus the extensive development work which has been done in this country on enriched fuels, provides the current technology on which can be estimated power costs from a plant that can be built. These costs are 11.89 mills per kilowatt-hour for a natural uranium gas cooled reactor system and 10.36 mills per kilowatt-hour for an enriched system—this latter figure has a 5.97 mills component for fixed charges, 3.21 mills for fuel cycle and 1.18 mills for operation, maintenance and insurance.

Since the AEC's studies show that enriched systems have a greater economic potential than natural uranium systems under U.S. utility economics, no attempt was made to determine the potential of the natural uranium fueled-gas cooled systems.

For the enriched system, the studies indicate that by increasing the bulk outlet temperature of the system from 1,050° F. to 1,200° F., by increasing the power density from 5 to 8 kilowatts per litre of core and by increasing the system pressure from 300 to 400 p.s.i., the capital cost component of the power cost could be reduced by 1.57 mills per kilowatt-hour to 4.40 mills per kilowatt-hour.

As in the case of other systems, the basic reductions in fuel cycle costs are predicted to be due to lengthening life and reducing fabrication costs. In this system, it was estimated that the life could be extended from 10,000 to 14,500 megawatt days per ton and that the fabricating cost for the elements could be reduced from $110 to $70 per kilogram of uranium. This would bring about a total reduction of fuel cycle cost of 0.40 mill per kilowatt-hour, to make this component of the cost of the "potential plant" 2.80 mills per kilowatt-hour.

A further cost savings was indicated in CO_2 can be substituted for He as the coolant. This would reduce operation and maintenance costs by 0.40 mill per kilowatt-hour. Based on all potential gains, the estimated cost of power from the 300 electrical megawatt "potential plant" would be 7.67 mills per kilowatt-hour.

The costs of the development program necessary to achieve this potential is of the order of $100,000,000 between 1959 and 1968. This is exclusive of the $14,500,000 research and development program which is aimed at the high temperature unclad fuel prototype being constructed by Philadelphia Electric for $24,500,000. In addition, it will be necessary to construct the $30,000,000 experimental proto-

type which has been authorized and which is under construction at Oak Ridge.

Construction of the 300 electrical megawatt "potential plant" could be initiated by 1966.

HEAVY WATER MODERATED NATURAL URANIUM SYSTEMS

The practical technology of heavy water moderation for power-producing reactors is not far advanced in this country. However, the basic technology for this system has been developed through research and development programs, and much useful engineering and scientific technology in this field is available from the design, construction and operation of the production reactors at Savannah River. In addition, a vast amount of basic and engineering information has been generated by Canada, who has placed major emphasis on this system. Taking all these factors into consideration, and recognizing that the figures do not have the same degree of backup as those based on current technology for other systems, it was concluded that the cost of power from a 300 electrical megawatt, pressure vessel, non-boiling plant built on 1959 technology would be 12.50 mills per kilowatt-hour of which 7.05 mills are for capital cost, 4.22 mills for fuel cycle, and 1.23 mills for operation, maintenance and insurance.

Because this system is in an early state of development, the potential gains which can be predicted with reasonable assurance are fewer in number and of less certainly than for other systems on which there is a greater background of technology. However, it was concluded that by the development of a pressure tube reactor instead of a pressure vessel type, and by achieving an increase in power density from approximately 26 kilowatts per litre, which was believed to be possible, to 35 kilowatts per litre, capital costs could be reduced by approximately 1.25 miles per kilowatt-hour to a level of 5.80 mills per kilowatt-hour.

The analysis also showed that it was reasonable to increase the exposure lifetime of the fuel from 3,850 megawatt-days per ton, assumed as possible with 1959 technology, to 7,000 megawatt-days per ton during the next few years, and also to decrease the cost of fabrication from $50 to $15 per kilogram of uranium. These improvements would lower fuel cycle costs by 3.01 mills per kilowatt-hour to a "potential figure of 1.21 mills per kilowatt-hour."

No decreases were predicted in operation and maintenance costs; however insurance could be lowered by .04 mill per kilowatt-hour, resulting in a new total of 1.19 mills per kilowatt-hour.

The cost of power from the 300 electrical megawatt "potential plant" is thus 8.20 mills per kilowatt-hour.

In order to achieve the gains indicated, it would be necessary, in addition to the program associated with the reactor project of the Carolinas Virginia Nuclear Power Associates, to undertake an $80,000,000 research and development program, between 1959 and 1967, and also to undertake a construction program in the neighborhood of $175,000,000. Construction of the "potential plant" could be initiated in 1965.

FAST REACTOR SYSTEMS

Technical feasibility of the fast reactor system has been demonstrated by operating experience of Experimental Breeder Reactor No. 1. In addition, the design and development programs which have been carried out for Experimental Breeder Reactor No. 2 and the Enrico Fermi Atomic Power Plant have provided the basis of a current technology on which could be based the design of a 300 electrical megawatt plant capable of producing power at a cost of 13.25 mills per kilowatt-hour. The components of this cost are 5.10 mills for capital cost, 7.10 mills for fuel cycle, and 1.05 mills for operation, maintenance, and insurance.

Capital costs may be lowered approximately 0.67 mill per kilowatt-hour by reducing the thickness of the reactor shield, by simplifying design of pumps and inert gas system, by improving and simplifying piping layout and fuel loading and unloading mechanism, by increasing the temperature rise in the reactor and the temperature drop through the intermediate heat exchanger and steam generator, by decreasing pump and pipe size, and by improvements in instrumentation.

Major cost reductions can be realized by substituting a cermet fuel for the Uranium—10 percent molybdenum alloy which is the fuel of current technology. The use of such fuel would reduce fuel cycle costs from 7.10 mills per kilowatt-hour to 1.99 mills per kilowatt-hour.

No credit was taken for lowering operation, maintenance and insurance costs. Total cost of power from a 300 electrical megawatt "potential plant" is 7.47 mills per kilowatt-hour.

In order to realize the potential gains of this system, it would be necessary to carry out a development program between 1959 and 1968 in the amount of approximately $160,000,000, exclusive of money spent on the Fermi plant, and in addition to build a prototype plant at an estimated cost of $55,000,000.

The 300 electrical megawatt "potential plant" construction could be started in 1968 or 1969.

THERMAL BREEDERS—AQUEOUS HOMOGENEOUS SYSTEMS

The studies indicated that technical feasibility of the aqueous homogeneous reactor system as a thermal breeder had not yet been demonstrated. Therefore, the cost of power from a plant based on current technology was not estimated. However, there was believed to be sufficient background of technology on this system to permit predicting, with, of course, somewhat less certainty than in other cases, the potential of this system. Power from a 300 electrical megawatt "potential plant" was estimated to cost 11.33 mills per kilowatt-hour of which 6.38 mills are due to fixed charges, 2.12 mills to fuel cycle costs and 2.83 mills to operation, maintenance, and insurance.

In order to achieve this objective, it would be necessary to undertake a broadly scoped research and development program in the amount of approximately $75,000,000 between 1959 and 1970, and in addition to construct a 5 to 10 megawatt experimental reactor (Breeder Reactor Experiment No. 3), a 110 thermal megawatt thermal breeder experimental reactor, and a prototype reactor plant of 125 electrical megawatt capacity. The cost of those plants is approximately $100,000,000.

On this schedule, it is possible that a 300 electrical megawatt plant could enter the design and construction phase by 1970 or 1971.

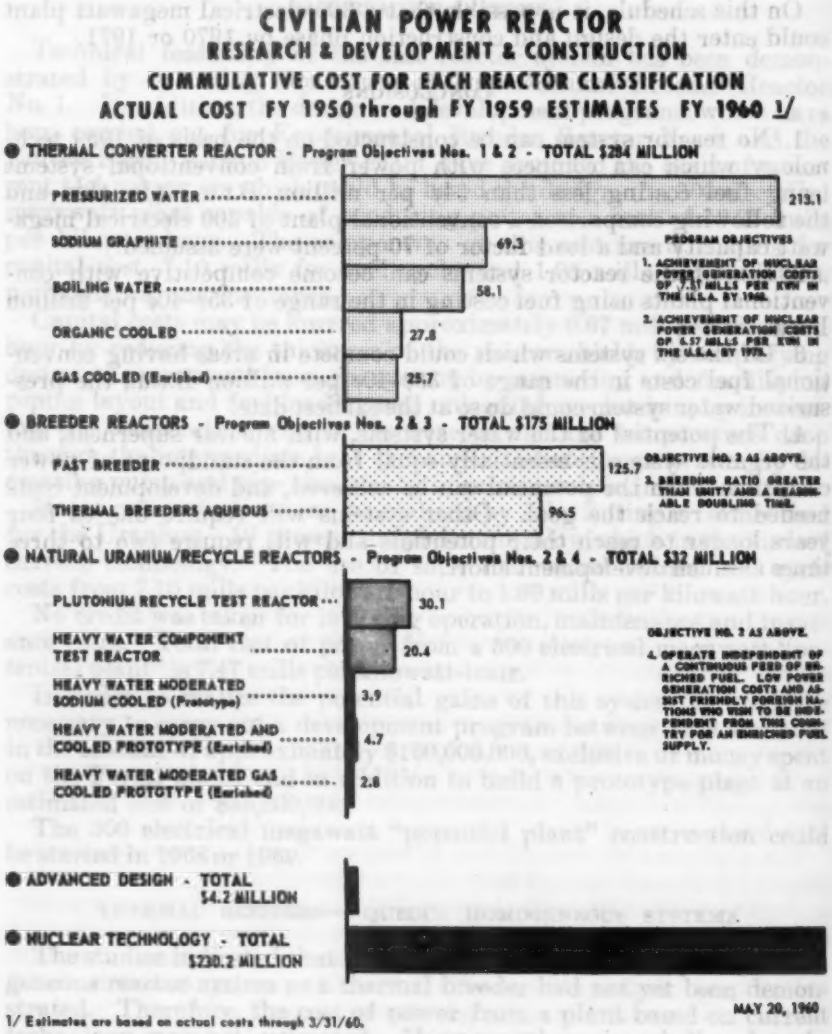
CONCLUSIONS

1. No reactor system can be constructed on the basis of 1959 technology which can compete with power from conventional systems using fuel costing less than 54¢ per million B.t.u. (In this and the following comparison a conventional plant of 300 electrical megawatt capacity and a load factor of 70 percent were assumed.)

2. Six of the reactor systems can become competitive with conventional plants using fuel costing in the range of 35¢–40¢ per million B.t.u.

3. Of the six systems which could compete in areas having conventional fuel costs in the range of 35¢–40¢ per million B.t.u., the pressurized water system could do so at the earliest date.

4. The potential of the water systems, with nuclear superheat, and the organic system is essentially equal from the standpoint of power cost, time when the potential can be achieved, and development costs needed to reach the goal. Other systems will require one to four years longer to reach their potentials and will require two to three times as much development effort.


CIVILIAN POWER REACTOR
RESEARCH & DEVELOPMENT & CONSTRUCTION
CUMMULATIVE COST FOR EACH REACTOR CLASSIFICATION
ACTUAL COST FY 1950 through FY 1959 ESTIMATES FY 1960 1/
● THERMAL CONVERTER REACTOR - Program Objectives Nos. 1 & 2 - TOTAL $284 MILLION
PRESSURIZED WATER
213.1
SODIUM GRAPHITE
69.3
BOILING WATER
58.1
ORGANIC COOLED
27.8
GAS COOLED (Enriched)
25.7
PROGRAM OBJECTIVES
1. ACHIEVEMENT OF NUCLEAR POWER GENERATION COSTS OF 7.57 MILLS PER KWH IN THE U.S.A. BY 1968.
2. ACHIEVEMENT OF NUCLEAR POWER GENERATION COSTS OF 6.57 MILLS PER KWH IN THE U.S.A. BY 1975.
● BREEDER REACTORS - Program Objectives Nos. 2 & 3 - TOTAL $175 MILLION
FAST BREEDER
125.7
THERMAL BREEDERS AQUEOUS
96.5
OBJECTIVE NO. 2 AS ABOVE.
3. BREEDING RATIO GREATER THAN UNITY AND A REASONABLE DOUBLING TIME.
● NATURAL URANIUM/RECYCLE REACTORS - Program Objectives Nos. 2 & 4 - TOTAL $32 MILLION
PLUTONIUM RECYCLE TEST REACTOR
30.1
HEAVY WATER COMPONENT TEST REACTOR
20.4
HEAVY WATER MODERATED SODIUM COOLED (Prototype)
3.9
HEAVY WATER MODERATED AND COOLED PROTOTYPE (Enriched)
4.7
HEAVY WATER MODERATED GAS COOLED PROTOTYPE (Enriched)
2.8
OBJECTIVE NO. 2 AS ABOVE.
4. OPERATE INDEPENDENT OF A CONTINUOUS FEED OF ENRICHED FUEL. LOW POWER GENERATION COSTS AND ASSIST FRIENDLY FOREIGN NATIONS WHO WISH TO BE INDEPENDENT FROM THIS COUNTRY FOR AN ENRICHED FUEL SUPPLY.
● ADVANCED DESIGN - TOTAL $4.2 MILLION
● NUCLEAR TECHNOLOGY - TOTAL $230.2 MILLION
MAY 20, 1960

1/ Estimates are based on actual costs through 3/31/60.

NOTE BY THE REVIEW STAFF.—In order to gain additional perspective upon atomic power, a brief questionnaire was sent to various industrial concerns directly involved in commercial atomic power programs. The good offices of the Atomic Industrial Forum were utilized as a focal point for the distribution of the questionnaire. Correspondence with the Atomic Industrial Forum, the questionnaire itself, and the replies appear below. The replies are grouped into three categories: consultants and engineers, manufacturers and service plant operators, and utilities.

LETTER FROM ROBERT McKINNEY TO FRANCIS K. McCUNE, PRESIDENT, ATOMIC INDUSTRIAL FORUM

During the recent Forum Conference, you offered to give me any appropriate assistance in conducting the Review of International Atomic Policies and Programs of the United States for the Joint Committee.

* * * * * * *

I would therefore like to request the Forum's assistance in compiling the views of your members as to:

1. When, if in a foreseeable time, such plants can be economically competitive in various sizes, types, and geographic classes of location, using agreed upon standard economic assumptions;
2. Whether any of the so-called nontechnical obstacles, such as patents, third party liability, etc., are in fact so fundamental in nature as to cause reconsideration of the desirability or feasibility of achievement of the President's original objective.

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LETTER FROM FRANCIS K. McCUNE, PRESIDENT, ATOMIC INDUSTRIAL FORUM, TO ROBERT McKINNEY

Thank you for your letter of December 10 in which you request the assistance of the Atomic Industrial Forum in compiling certain information for use in connection with your review of international atomic policy and programs of the United States for the Joint Committee.

Naturally the Forum is most anxious to cooperate with you in any way that it can. * * *

Questionnaire

1. When, if in the foreseeable future, do you believe atomic power plants can be economically competitive?[1]

Please take into account: (*a*) time periods such as 1960–1965, 1965–1970, 1970–1975, and after 1975; (*b*) plant sizes under 100 megawatts, between 100 and 250 megawatts, and larger than 250 megawatts; and (*c*) geographic locations such as the United States, Europe, Latin America, Asia, and Africa.

In your response, please identify any nuclear or nonnuclear factors which you think might accelerate or slow down achievement of economic nuclear power.

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[1] So as not to restrict or limit your response, we have not provided space for comment on the questionnaire. Please use other paper. Conciseness, however, will be appreciated.

2. In your opinion, are any of the so-called nontechnical obstacles, such as patent policies, third party liability, licensing and regulations, security restrictions, etc., so fundamental in nature as to cause reconsideration of the desirability or feasibility of achievement of the objectives stated by the President in his speech of December 1953; namely, the development of economically competitive atomic power and the installation of a substantial nuclear-powered generating capacity throughout the world? [1]

UTILITIES

1. I believe atomic power plants *can be* economically competitive but whether or not they *will be* is another question. They can be competitive if one is safe in assuming that our national policy, as expressed in the Atomic Energy Act of 1954, is consistently implemented by our Federal Government particularly insofar as encouraging the active participation of private industry is concerned. This does not imply the necessity of subsidies to industry but rather the progressive removal of roadblocks in the form of uncertainties as to Federal policy and unduly burdensome procedures in connection with licensing and other regulations. There appear to be reasonably good prospects for progressive reductions in both capital and fuel costs which conceivably would make it possible for plants of 250 megawatts and larger to be economically competitive in a considerable part of the United States and a large part of Europe by plants whose construction is started about 1970. Plants of smaller size would probably not be competitive until later, if indeed they were ever needed if the load growth continues as generally expected. I am not sufficiently familiar with the conditions in Latin America, Asia, and Africa to express an opinion.

2. As to the so-called nontechnical obstacles, it seems to me that—

(*a*) Present patent policies are more of an irritation than an obstacle.

(*b*) Third party liability has been reasonably well taken care of insofar as installations in the United States are concerned and if similar provisions are made in foreign countries and incorporated in international agreements this should present no fundamental obstacle.

(*c*) Licenses and regulations need present no obstacles if handled in a reasonable manner both nationally and internationally.

(*d*) Security restrictions seem to be on their way out and if this trend continues should present no problem.

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(1) It is my firm conviction that reactor plants of a size between 100 and 250 megawatts-electrical will have become fully competitive in the high cost conventional fuel areas of the United States by 1965. This goal, however, will be attained in water reactors without nuclear superheat. Most reactor plants built so far have thermodynamic efficiencies of only about 25 percent. Any increase in the overall efficient of the plant—and this is extremely important—will

See footnote 1 on p. 1157.

automatically result in a proportional lengthening of the lifetime of the fuel elements in terms of useful energy produced, while also reducing capital costs per kilowatt of installed capacity. Today, nuclear fuel costs are already lower than conventional fuel costs, but this saving is more than offset by the higher fixed charges for interest and depreciation of a nuclear powerplant versus those of a conventional plant. Increasing the efficiency is one sure way of bringing atomic energy to the threshold of competition with conventional powerplants.

I assume that after the reactors presently being built are completed, units larger than 250 megawatts-electrical will be built and this will further tend to reduce the cost of nuclear power and make such reactors more than competitive by 1970 and foster their use in medium cost conventional fuel areas of the United States.

Once the point of competition is reached, I can see a big increase in nuclear plant capacity in the United States, in continental Europe, in England, and in Japan.

Frankly, as much as the International Atomic Energy Agency is interested in small size reactors of 20 to 50 megawatts-electrical, I cannot see how they can be competitive now in the underdeveloped nations of the world. Neither can I visualize the construction of such small reactors in Latin America. These nations should definitely wait until the operating results are known of the various small nuclear powerplants at Elk River, Minn.; Piqua, Ohio; Parr, S.C.; and in York County, Pa. I have great confidence that the gas-cooled closed-cycle reactor concept presently being developed by General Atomic and Bechtel jointly may be the answer. This reactor will be well suited for the smaller sizes in which underdeveloped nations will become interested; it will have an efficiency of about 32 percent. For this type of reactor, as for the water reactors, high efficiencies will be the key to competitive nuclear power.

Although I acknowledge the efforts of utility companies in continental Europe as in the United States, I would like to see an even greater willingness on their part to embark on more reactor construction. What has been done so far in this country and in Europe represents a genuine effort, but is not yet quite enough. There must be more utilities willing to build reactors of the more advanced types. I submit that more Government encouragement is needed to achieve that goal in the more technically advanced nations. I can think of no better way of doing this than by following through on the suggestion made by Mr. John McCone to have Government assistance up to 50 percent of the capital cost of a nuclear powerplant with a ceiling of say 75 percent of the excess capital cost of the plant over the cost of a conventional plant of the same size. This is a simple formula which I am sure would induce more utilities to build reactors here and abroad.

(2) To my way of looking at the picture, these so-called nontechnical obstacles are not the important ones. The only obstacle I see is purely of an economic nature. Reactor plants are not yet competitive, particularly when they are of small size—20 to 50 megawatts-electrical. To the extent that the President's speech of December 1953 called for the development of nuclear power in underdeveloped nations, I think it was unrealistic for the reasons stated under (1)

above. The speech was, of course, of much broader scope and indeed, one of the most inspiring ever given by any man. The eyes of the underdeveloped nations are focused on what is being done in this country, in continental Europe and in England. It will be only after atomic plants have become competitive in those areas that the under developed nations of the world will begin to generate an active interest in the smaller sized plants.

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Question 1

We believe that atomic powerplants of all the sizes mentioned can become economically competitive in the United States and Europe during the latter part of the period 1965–70.

The sequence of events likely will be approximately as follows:

1. The present power reactor projects will come into operation and provide information which will permit the design and construction of greatly improved second and third generation plants in the period 1960–64.

2. Although these second and third generation plants likely will not be competitive, they will come close and provide additional advances during the period 1965–68 which will permit the design and construction of plants that probably will be competitive. The advantage, if any, of such plants may be small and we would not expect their widespread use until their economic status is clearly demonstrated.

In any discussion of "economically competitive" nuclear power, it should again be emphasized that the basis on which power costs are computed greatly influence results. Variations in such items as annual plant factor, fuel rental charges, fixed charges on investment, conventional fuel costs, etc., can have a significant effect on the time of achievement of economic nuclear power.

We believe that the fast breeder reactor can be carried forward with such a time schedule and ultimately will become one of the basic factors of the atomic power industry. Other types of reactors which at present are in the advanced state of development, may progress a little faster than the breeder, but still within the same approximate time schedule.

Many factors including natural resources and political and social unrest enter into atomic power for Africa, Asia, and Latin America. Very large hydro resources are available at low cost in parts of Africa and elsewhere, and there is serious doubt whether sufficient technical knowledge will exist in some of the countries which may be concerned to justify an endeavor to use atomic power under any circumstances.

Question 2

We see no obstacles within the United States which will prevent the achievement of the objectives set forth by President Eisenhower. However, we do believe that our policies with respect to patents should be modified to provide normal patent protection, and that the licensing and regulation procedures may need extensive modification and liberation as we gain more practical experience with reactors.

Most of the Western European countries seem to be moving forward with atomic power, but, as mentioned in our answer to question 1, we are unable to judge when it may be practical to undertake the use of atomic power in many oversea countries.

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The cost of nuclear power produced by Dresden and other plants now under construction, although not competitive, will be substantially lower than that produced by earlier models. We believe this trend will continue and that within 5 to 10 years a number of nuclear units will be ordered on the basis of a strictly competitive power cost. This will occur first in areas where the cost of fossil fuels is relatively high.

Our experience indicates that because of high containment and shielding costs and because of neutron economy, units larger than 250 mw. will be the first to become competitive.

Assuming that safety standards for nuclear plants are made realistic and the regulatory process of enforcing these standards does not throttle progress, it should be possible to build nuclear power-plants closer to the load center. Ability to build plants in populated areas should hasten competitive nuclear power through reduction in transmission costs. It would have the further advantage of making it possible to avoid some of the mounting costs of overcoming air pollution from fossil plants.

It appears likely that the delivered cost of coal and oil will rise. On the other hand, the discoveries of additional uranium ores, coupled with improvements in refining, enrichment, and fabrication and chemical separation processes, should reduce the cost of nuclear fuel. Studies initiated by the Atomic Energy Commission already are underway to determine the possibility of getting private industry into the chemical separation field. These factors appear likely to hasten the advent of competitive nuclear power.

In the area of licenses, indemnity, and insurance, there are no basic deterrents. The legislation under which the Atomic Energy Commission operates, namely, the Atomic Energy Act of 1954, is sound, generally speaking, and provides a good framework upon which to build a constructive program.

In administrative detail, however, there are technical problems which might become troublesome.

One of these is in the area of licensing. There are too many subagencies of the Atomic Energy Commission involved in the licensing procedure, as the result of which it is extremely cumbersome. The Commission is aware of this problem and, I have no doubt, will solve it.

The indemnity legislation is sound and, despite some recommendations to the contrary, does not require any amendment. The only problem we see in this area is the possibly prohibitive cost of private insurance. The insurance industry has set up an atomic insurance organization, the cost of which weighs heavily in the premiums being paid by the owners of a very small number of private atomic plants.

This will be a problem until there are more plants completed and until experience demonstrates that the actual third party liability and plant risks are nominal.

In the meantime, insurance costs are high. At our 640,000-kilowatt Ridgeland conventional station, our insurance costs are 0.001 cent per kilowatt-hour. For our Dresden station, we have been budgeting insurance costs which will equal 0.05 cent per kilowatt-hour, or 50 times as great. This, of course, is a considerable hurdle for atomic power to overcome. Moreover, we have recently been informed that the premium may even be higher. We have taken this problem up with the insurance industry and have hopes that something will be done to keep the costs within reason.

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1. When, if in the foreseeable future, do you believe atomic power plants can be economically competitive?

Atomic powerplants are expected to be economically competitive in the period 1970 to 1975 in those areas of the world where the fuel costs are now in excess of 35-cents per million B.t.u.'s. The fossil fuel costs are expected to gradually increase, whereas the atomic power costs are expected to gradually decrease. Any sudden change in the availability of fossil fuels would affect the achievement of economic nuclear power.

2. In your opinion, are any of the so-called nontechnical obstacles, such as patent policies, third party liability, licensing and regulations, security restrictions, etc., so fundamental in nature as to cause reconsideration of the desirability or feasibility of achievement of the objectives stated by the President in his speech of December 1953, namely, the development of economically competitive atomic power and the installation of a substantial nuclear-powered generating capacity throughout the world?

It appears as though the most important nontechnical considerations are in the areas of licensing and regulation and public acceptance. Licensing and regulation provision should be adequate to assure safety for the general public and the plant operators, but should recognize that the more restrictive the regulations become the slower will be the progress toward economic nuclear power. General public acceptance should be fostered so that the public believes that nuclear powerplants are good neighbors rather than undesirable installations in the community.

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In answering your inquiry of January 26th seeking information for Mr. McKinney as to when I think atomic power will be economically competitive, I ought to omit my opinion regarding timing for different geographic locations around the world. The reason is that I am not well enough informed on foreign fuel costs, and any answer I would give would be pure speculation.

As a substitute, however, I submit the following table as my judgment:

Size of unit	Conventional fuel cost, cents per million B.t.u.	Time period when atomic units will be competitive
250 megawatts and over	Over 50	1965
Do	40 to 50	1965–70
Do	30 to 40	1970–75
100 to 250 megawatts	Over 50	1970
Do	40 to 50	1970–75
Do	30 to 40	1975–80
Under 100 megawatts	Over 50	1975
Do	40 to 50	1975–80
Do	30 to 40	1980–85

Applying the fuel costs of the specific areas might give an indication when atomic power may become competitive at those locations. This applies to the United States as well as foreign countries.

Although such items as patent policies, third party liability, security, restriction, etc., i.e., nontechnical obstacles, have an appreciable restrictive influence, they are not a great deterrent. It is more a matter of dollars and cents' economics. Nevertheless, liberalizing patent policies, licensing and regulations, and security restrictions should be pursued, as anything we do will be of some benefit in promoting the development of atomic energy.

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MANUFACTURERS OF REACTORS, COMPONENTS, AND FUEL, AND SERVICE PLANT OPERATORS

1. There are certainly areas in the world where atomic power can compete economically with fossil fuels today. Each potential installation must be examined on its merits.

For example, we are building a plant under the Army Power Reactor Program * * *. If such a plant were placed at a base in the Arctic or Antarctic, its power costs over a period of years would clearly be lower than those of conventionally fueled systems. This is true in spite of the fact that PM–1, as it is designated, is in the one-megawatt range, and talk of economic savings is generally associated only with much larger plants.

In areas where bulk transportation is less expensive and less difficult, of course, it is only possible for nuclear systems to compete in the very high power ranges. Nevertheless, it appears that we are near or at the break-even point in the Far East and in some sections of Latin America.

In the United States, there are some areas where our company's studies indicate that nuclear reactors can produce process heat now at a rate lower than that of conventional plants; but the story is different in the case of electrical generation. It is virtually impossible to predict the speed at which the economics of the fuel cycle can be improved. The 1970–75 period looks promising now, but so did the 1960–65 period 10 years ago.

2. No. There is certainly no reason whatsoever to reconsider the desirability of the objectives; and their feasibility is simply a matter of time.

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(1) When, if in the foreseeable future, do you believe atomic power plants can be economically competitive?

In the following table for each rating and each geographical location there are given two time periods related to two definitions of "competitive." For the first periods in parentheses "competitive" means economically practical over the anticipated life of the plant (although not always with the first fuel load), in some areas with some, but not all, widely used accounting procedures. For the second periods economically competitive is construed to mean that the cost of energy is equal to, or less than, the cost of energy for the upper 25 percent of new thermal additions.

	100 megawatts	100 to 250 megawatts	250 megawatts
United States	(1965–70) 1970–75	(1960–65) 1965–70	(1960–65) 1965–70
Other	(1960–65) 1965–70	(1960–65) 1960–65	(1960–65) 1960–65

The most important factor in the acceleration of the program domestically as well as in the foreign market is probably a record of success in the plants going on the line within the next three years. One of the more important threats to acceleration is the licensing procedure. However, this writer believes that industry and Government collectively can streamline these procedures with practice.

(2) In your opinion, are any of the so-called nontechnical obstacles, such as patent policies, third party liability, licensing and regulations, security restrictions, etc., so fundamental in nature as to cause reconsideration of the desirability or feasibility of achievement of the objectives stated by the President in his speech of December 1953, namely, the development of economically competitive atomic power and the installation of a substantial nuclear-powered generating capacity throughout the world?

We do not consider any of the so-called nontechnical obstacles so fundamental as to call for reconsideration of the feasibility of the worldwide growth of nuclear power generation. However, there will be required unrelenting pressure on provision of proper liability protection, the establishment of safety standards, the adoption of OEEC and EURATOM conventions, etc.

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I believe atomic powerplants can be economically competitive within the ten-year time scale which generally is used in discussions of this type. I do not believe that this can be done alone by building small prototypes nor do I believe that it can be done by dissipating our efforts in the building of plants in countries other than our own. Especially, I believe that if there is money available in any form to sub-

sidize the first steps in nuclear power that this should be used for development and construction of plants in the United States. I have never accepted the thesis that we could hope to either export plants or to add substantially to our technology by subsidizing, in any form, the construction of plants in foreign countries before we have made them useful in our own.

I believe the most serious nonnuclear factor which I now can identify which might prevent us from realizing our goal of economically competitive power is the notion that somehow small reactor powerplants can compete with very large boiler plants. The challenge which we face is one essentially of choosing the time, circumstance, and the financial arrangement which will permit us to build large-scale nuclear power plants. Only when we have arrived at a situation where this will be possible can we hope to approach achievement of economic nuclear power.

The third-party liability arrangements and the security arrangements now existing are satisfactory, as far as I can tell, for the development of civilian nuclear power. The patent policies are far from satisfactory, and the licensing regulations are too complex. I believe that experience will show how the licensing regulation matter can be smoothed out, and that it ultimately will not be anything more than an expense. On the premise that our atomic industry should and could make further investments in the future of nuclear power, I believe our policy on patents, especially where government-assisted work is involved, will continue to have a stifling effect.

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1. The question, "When, if in the foreseeable future, do you believe atomic powerplants can be economically competitive?" points up the need for agreement on a definition of "economically competitive." I believe that a suitable definition of "economically competitive" must have realistic significance in the power economy of the area considered if it is to have any really useful meaning.

In many respects it is unfortunate that a focus of attention has been concentrated on this issue that in my opinion has no "yes" or "no" answer. Evidence to date suggests that each power situation will have its own particular solution in terms of nuclear power and that nuclear power will generally find its place in a gradual fashion along with our current combination of hydroelectric and fossil-fuel-fired power stations.

The cost pattern for capital equipment for various types of nuclear powerplants is already evident. The general agreement now seems to be that fuel economy is the critical issue. This situation places emphasis on handling all nuclear fuel cycle costs—from concentrate to fuel element and fuel reprocessing as well—in a manner that will permit the development of realistic costs. Commercial handling of the nuclear fuel cycle must parallel the marketing conditions for the fossil fuels cycle if a comparison of power costs from nuclear fuels and conventional fuels is ever to be meaningful.

2. I do not believe that the nature of the concern over such matters that you have identified as nontechnical obstacles (patent policies, third-party liability, licensing and regulations, and security restrictions) is such as to require reconsideration of the goals of our international atomic energy program as expressed by the President in 1953. However real these various problems are to both industry and to Government, I think it important to recognize that they are only operational mechanics which I am confident can be viewed in proper perspective in the future. The accomplishment of the President's goals for our international atomic energy program insofar as they pertain to power generation from nuclear energy is fundamentally an economic situation.

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The writer believes that nuclear power reactors of five to 10,000 kilowatt powerplants will be competitive in the period 1960 to 1965 in certain remote areas, particularly military bases, if all costs are considered. This assertion is believed to be true when it is realized that in certain remote areas the fuel for conventional fuel plants is delivered by fuel-oil drums dropped from aircraft with it consequent shrinkage on landing.

Between 1965 and 1970 plants of 25,000 kilowatts will become competitive in remote areas where transportation is difficult, yet where considerable population resides. The period from 1970 to 1975 should see competitive nuclear power in the very large powerplants of 250 megawatts and above in areas of dense population with heavy commercial and industrial electrical loads, both in the United States and Europe.

The recent availability of large supplies of oil and gas in Canada, Northern Africa, France, West Germany and lower Italy, together with the anticipated increase in oil exploration in the Argentine and Brazil and its possible finding, would indicate that the decade from 1960 to 1970 will be a period of very plentiful fossil fuel supplies.

Another nonnuclear development, which will, it is believed delay nuclear power through the possibility of making more available petroleum fuel is the possible exploitation of more efficient use of fossil-fuel prime movers, and further refinement of fuel cells and magnetohydrodynamic generation.

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1. (*a*) I believe that atomic powerplants can become economically competitive during the period 1970 to 1975. This belief is based upon the assumption that the second generation of power reactors will have demonstrated satisfactory performance in the period 1968–70 and that a sharp increase in the growth curve of nuclear plants will occur during or shortly after this demonstration.

(*b*) I believe that plant sizes of 100 to 250 megawatts will prove to be the most feasible.

(*c*) I also believe that the industry will develop in both the United States and Europe during the periods indicated.

In my opinion, the greatest single factor that will contribute to economic atomic power is the extent to which government remains competitive in the field with the efforts of private companies. However, at the same time, I believe that the government's power demonstration program is an essential part of the program but should go ahead working through the existing channels of private business. I believe if the government continues to undertake the construction of powerplants at its own sites and without the stimulus of private competition that industry may very well sit back and wait while the government does the job at a slower pace.

2. While the so-called nontechnical obstacles such as patent policies, third party liability, licensing and regulations, and security restrictions are very important, I do not believe they are so fundamental in nature as to warrant reconsideration of the desirability or feasibility of achievement of the objectives stated by the President in his speech of 1953. This is, they should be looked upon as more of a "nuisance factor" for which answers will be readily found provided there is sufficient motivation as determined by the rate of progress of our technical program.

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1. It is my considered opinion that design can be started on economically competitive [1] atomic powerplants in the following areas and sizes as listed:

	100 mwe	100–250 mwe	250 mwe
United States high fuel-cost area	1964	1962	1961
United States in general	1967	1964	1963
Europe	(1)	1962	1961
Latin America [2]	(1)	(1)	1962
Asia [2]	(1)	(1)	[3] 1961
Africa [2]	(1)	(1)	(1)

[1] Insufficient knowledge to form a strong enough opinion for reporting.
[2] The general background of technical know-how available in Latin America, India, and Africa may impose restrictive limitations on the earliest feasible date that economically competitive atomic power will be available. Accounting methods and nationalism will also influence such a date.
[3] For India only, and based on U^{235}–U^{238} cycle. Th^{232}–U^{233} cycle will take 5 to 10 years longer.

2. Comments on the so-called nontechnical obstacles are as follows:

(*a*) *Patent policies.*—These are not considered sufficiently restrictive to be detrimental to the goal stated.

(*b*) *Third party liability.*—This appears to be currently resolved in the U.S. by including the fuel manufacturers under Government indemnity. It will continue to be a major obstacle to U.S. participation in international atomic power.

(*c*) *Licensing and Regulation.*—The major obstacle here is the compulsory disclosure of proprietary processes to one and all in the public document room. This disclosure of company confidential information is also a contention in the present inspection requirements of the USAEC, with the same problem potentially in the forthcoming state control.

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[1] "Economically competitive" is interpreted to mean competitive with current markets of fossil fuels. No allowance has been made for the situation where the current market price of fossil energy may be lowered by spending only a fraction of the capital cost of an atomic power industry on increasing productivity of fossil fuels, thus making the atomic power no longer competitive.

(*d*) *Security restrictions.*—If current declassification continues to accelerate, the problem in this area will tend to be minimized. Delay of information available from public organizations such as National Laboratories and other AEC contractors is a serious handicap to reaching the desired goal with an optimum timing.

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1. My remarks about larger powerplants are based on personal rather than company analysis and are predicated on a knowledge of the development of other types of powerplants over a long period of time rather than specifically with reference to particular atomic powerplants or cycles.

I believe atomic powerplants above 100 megawatts will become economic in the United States between 1970 and 1975. I see no reason to expect that the larger type plants will better this by any substantial amount if the comparison is made with comparable fossil fuel plants.

While I appreciate that the thinking generally is that due to the higher cost of electricity in Europe today economic equality of cost of production between nuclear and fossil fuel plants should come earlier, I have begun to question the validity of this assumption. It is true that fuel costs in Europe have been higher and capital costs which affect the nuclear powerplant so greatly have been lower because of labor rates particularly, it appears that fuel costs are due for something of a drop and the capital cost differential has not proved sufficiently attractive to get a substantial program rolling even with U.S. assistance. I can see no real reason why Latin America, Asia, or Africa should prove more advantageous. The cost of fossil fuel delivered at the selected location would certainly have a more obvious effect.

The really small size nuclear powerplant currently being built as a pressurized waterplant can compete economically against diesel engines only in areas of really high cost diesel fuel. Estimates vary widely as to just what this cost is and how it might be accurately calculated, but it appears to be somewhere in the neighborhood of $1 a gallon. Logistic considerations are much more important than economics in this area. It appears, however, that the steam nuclear plant can no more be competitive here than the steam-fossil fuel plant has been in the past. A factory assembled compact portable plant is required and it is not likely that such a plant will appear in competitive form before 1975.

The most important factor to consider in achieving the above program is the amount of support afforded by government to insure a continuing program both in research and development and in the construction and operation of actual plants. Even to reach the estimates in the preceding paragraphs a program comparable to the one which has been in force would be required.

A great deal will be learned from the operation of the large plants now under construction. I am, however, heartily in accord with the present thinking which is toward the construction of smaller plants from which much can be learned even though the particular size of plant constructed may never be expected to become economic.

2. I have been very much concerned with the nontechnical obstacles, particularly third party liability. I do not believe that up to this

point any of these factors have substantially retarded progress but I am sure that they will exert an increasing influence in this direction unless greater incentives from patents can be afforded to manufacturers. Third party liability now appears to be pretty well resolved except for components manufactured for military reactors. Licensing regulations, security restrictions, etc., are annoying but unless they are so tightened up as to increase the actual overall cost of construction and components substantially, it would not appear that they would have any fundamental effect on the development of economically competitive atomic power and the installation of a substantial nuclear power generating capacity throughout the world.

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1. Competitive nuclear power before 1965 appears unlikely. Economically competitive plants will probably be demonstrated in the high power cost areas of the U.S. in the 1970–1975 time period. Large scale construction of nuclear plants will probably be underway in this same 1970–1975 time period in Europe where power costs are generally higher than in the U.S. Construction of plants in other geographic locations will probably follow economic demonstrations in Europe and U.S.

Plant sizes under 100 megawatts will likely be found useful and competitive in rural areas where large central stations would be impractical. The lowest cost per killowatt-hour will be achieved in the large central stations installation of more than 250 megawatts. The place for plant size between 100 and 250 megawatts is less well defined and such plants will probably find their economic place after the other two categories are already established.

There are nonnuclear factors which may affect the vigor with which the U.S. programs are prosecuted. These are—

1. Which political party is in charge of the national administration;
2. The emphasis which the Russians place upon their atomic power programs;
3. Possible occurrence of a situation analogous in effect to the Suez crisis of late 1956.

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In reply to your request for an opinion on the future of nuclear power, to assist Mr. McKinney in his study, I would like to say that he will undoubtedly find as many opinions as there are interested individuals in the United States. One of the problems, it seems to me, is that all of us are operating pretty much in the dark at this time. We are valiantly attempting to predict when nuclear power costs will reach a figure of approximately 8 mils, when the only real solid datum point which we now have is the Shippingport information. All of us know that our facts will be much more reliable when the first information is received on the cost of power from Yankee, Dresden, and the like. Until that time, it seems to us that all guesses as to the future are subject to relatively large errors.

It is our opinion and our planning is based on this opinion, that we will not see extensive commercial use of nuclear energy to generate electric power before 1970. This is based upon a belief that commercial electric utility organizations will not continue to invest in a noneconomic power source. It is also based upon our conclusion that at least two more "rounds" of reactors must be built, each taking advantage of proven improvements of the previous round before construction and operating costs can be brought down.

We must all recognize that there are certain disadvantages in using nuclear energy in addition to the present cost problem. Utilities can not be expected to invest aggressively in nuclear power unless the cost advantage of nuclear power will offset the price of electricity from fossil fuels and, in addition, will compensate for the extra problems and difficulties of a nuclear plant. In summary, this means after 1970.

We do not feel that the differences among plants of 100 megawatts, 200 megawatts, and 300 megawatts will be the significant factors in determining the beginning of a nuclear market. Other factors at this time seem to outweigh the size question to a great extent.

It is our opinion that the so-called nontechnical obstacles are not so fundamental as to be responsible for the time scale in achieving economic nuclear power. It is true that the many problems centering around patents, licensing, security, and the like, serve to discourage qualified companies and individuals from participating heavily in nuclear programs. It is unlikely that this factor will delay the achievement of economic power to any great extent. After all, the AEC in its laboratories and through its direct contracts, is purchasing large amounts of research and development and, in a general way, these purchases represent progress.

I think it is very likely that the full potential of nuclear power will not be achieved until some new scientific approach is found to make use of energy released in fission. Today's nuclear plants merely substitute the fissioning of uranium for the burning of fossil fuels. Nuclear energy has certain other unusual characteristics which we are not making use of through this approach. Hence the real possibility that direct conversion or some other ingenious idea may extract power from the atom far more economically than present reactor techniques. These ideas would revolutionize our present approach, and they too probably could not be successfully achieved before 1970.

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1. We believe that large size plants with power capabilities above 250 MW can be competitive in areas having very high cost fuels and requiring large blocks of power in the period from 1965 to 1970. It is expected that some of these plants will produce power toward the end of the 1960–1965 period but they will not have reached their equilibrium power conditions and hence will not demonstrate economic power during this earlier period. The particular areas in which these comments apply include California and New England in this country, and Japan, Italy, and some areas in western Europe.

There may be areas in Latin America and Asia which have high cost electricity and which can use large blocks of power. Economic power in the 1965–1970 period could also be achieved in these areas.

It is probable that nuclear plants in the 100–250 MW range will demonstrate feasibility during the period from 1970 to 1975. The application of these plants probably will be more widespread geographically. However, it is not expected that this size plant will be built in areas that can use the larger plants inasmuch as the economics are distinctly favorable to the large plants.

It does not seem probable to us that nuclear plants under 100 MW will find a large market in very many areas of the world when compared to the less expensive conventional plants that can be installed and operated.

There is one significant economic factor that will tend to slow down the development of atomic power. This is the gradual reduction in fossil fuel prices and in transportation costs that will occur due to the threat of atomic power displacing conventional fuels. There are already indications of increased attention to cost reduction in these areas.

2. We do not believe the so-called nontechnical obstacles such as patent policies, licensing and regulations, and security restrictions are such as to cause reconsideration of the desirability or feasibility of achieving the objectives stated by President Eisenhower in his speech of December 1953. Because of the activity abroad in proposed OEEC and Euratom third party liability treaties, we see hope of a solution to the problem, enough hope to also justify a negative answer to that question.

In general, the probable advantage in an atomic powerplant will be in lower cost per million BTU of the energy supply. It has the disadvantage of higher investment cost, reprocessing fuel cost, and waste disposal. Many engineers point out the advantages of greater size in cost of an atomic plant, but it is doubtful if this is much of a factor if comparison is made with a conventional steamplant of equal size, as these plants are also cheaper in large sizes.

On a steamplant using 10,000 BTU/KWH fuel for power production and using 12% fixed charges, about 20¢/"MM" BTU on fuel cost could be justified by $100/KW increase in investment. At the present time, an atomic powerplant will probably have more than $100/KW increased investment. To simplify the problem, we will assume a fuel cost saving of 20¢/"MM" BTU will be required to make nuclear power economical as compared to conventional stations.

On this basis, the coal-producing states such as the Midwest will not be economic for nuclear power as long as coal reserves last. The areas of high fuel cost, such as New England, Florida, or remote areas, might be economic now.

The advantage in favor of atomic power may increase by 1970–1975 because of developments reducing the cost of building such plants as more is learned about their requirements. Any new inventions making possible power generation direct from heat without use of the steam cycle would obviously change this picture quickly. This

does not appear likely in the near future. Due to government interest in this development, it seems that the nontechnical obstacles will be satisfactorily answered.

By 1975, it would seem that economically competitive nuclear power might be possible in, say, 20 of the 50 states.

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1. Our reply to this question is given in the attached tabulation. We have not made a recent economic analysis, and since the factors that enter into an analysis are subject to continual change, we do not represent our reply as anything but an opinion.

2. Nontechnical problems, such as contract practices, patent policies, third party liability, particularly in the international area, licensing regulations and procedures, security restrictions are impediments to the achievement of the objective stated by the President in his speech of December 1953, but we do not feel that they should be permitted by Government and industry to become insurmountable obstacles to the feasibility of achievement of these objectives. Solutions to these problems would permit and encourage private industry to participate to the greatest practical extent in atomic energy development in accordance with the stated objectives of the Atomic Energy Act of 1954. A cooperative approach by Government and industry could lead to the resolving of these obstacles, although with the delay already suffered in the achievement of the stated objectives.

OPINION OF PROSPECTS FOR ECONOMIC POWER

Power Range	Location	Period 1960 – 1965	1965 – 1970	1970 – 1975	After 1975
Under 100 MW	U.S.A.	—	Regions of highest fossil fuel cost		
	Europe	Regions of highest fossil fuel cost	Some European countries →		
	Asia	Regions of highest fossil fuel cost	Some Asian countries →		
	South America & Africa	—	Countries of high fossil fuel cost →		
100 – 250 MW	U.S.A.	Regions of highest fossil fuel cost	Some areas	Some areas	Some areas
	Europe	Regions of highest fossil fuel cost	Many countries	Many countries	Many countries
	Asia	Regions of highest fossil fuel cost	Many countries	Many countries	Many countries
	South America & Africa	—	Some developed countries	Some developed countries	Some developed countries
Over 250 MW	U.S.A.	—	Many regions	Many regions	Many regions
	Europe	—	Most countries	Most countries	Most countries
	Asia	—	Developed countries	Developed countries	Developed countries
	South America & Africa	—	—	Developed countries	Developed countries

Question. When, if in the foreseeable future, do you believe atomic powerplants can be economically competitive?

Answer. I believe that nuclear powerplants of small size will be economically competitive first in Asia within the period 1960 to 1965 and in Europe in the period 1965 to 1970. Sometime after 1970 nuclear powerplants may be economically competitive in the United States in small plant sizes located where power costs per KWH at the bus bar are in the 6 to 7 mil range or higher.

Question. In your opinion, are any of the so-called nontechnical obstacles, such as patent policies, third party liability, licensing and regulations, security restrictions, etc., so fundamental in nature as to cause reconsideration of the desirability or feasibility of achievement of the objectives stated by the President in his speech of December 1953, namely, the development of economically competitive atomic power and the installation of a substantial nuclear-powered generating capacity throughout the world?

Answer. The nontechnical items mentioned in the question are generally obstacles in the development of economically competitive atomic power. I am sure that the general intent of the regulations is excellent, but the detailed administration of them and some of the detailed implications of the principles make it difficult to make progress in developing competitive nuclear power. More incentive should be provided by allowing greater opportunity for private industry to acquire patents in the atomic energy field. More protection against third party liability is needed. Also, it should be easier to obtain such coverage. The licensing regulations and security restrictions should be administered in such a way as to remove the so-called "redtape" which impedes progress without substantially adding to the general intent of such regulations and restrictions.

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1. Answer to question 1 involves several factors, at least two of which are of primary importance—

(*a*) Location of atomic powerplant: I doubt if such a plant can be built—of any size—in the best coalfield of the United States during the 20th century—that would be economically competitive.

(*b*) Size of power plant: I doubt if a 100-kilowatt powerplant would ever be economically competitive anywhere.

The direct answer to question 1 depends on the above and many other factors.

I would like to condense my answer and prediction in a good diagram but that would require use of a three-dimensional unit. I will attempt to compromise in a quickly drawn sketch—attached.

In this sketch I have used the plant size and time intervals as suggested by you. My terms "US–1" and "US–2" represent respectively (1) selected sites in the United States, and (2) most of the rest of the United States. Terms "X–1" and "X–2" represent European or Japanese sites on the same basis. I cannot estimate on other parts of the world where I believe there are but a limited number of sites where

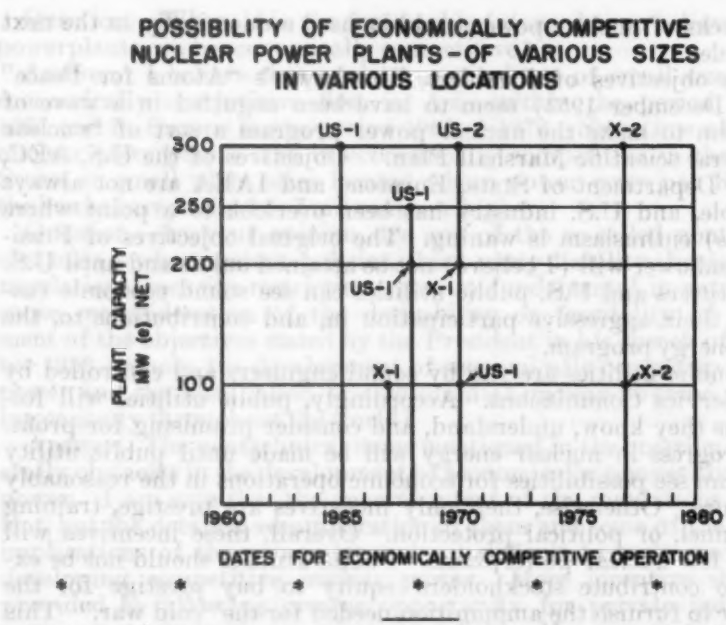
large blocks of nuclear power could be used economically in the next two decades.

2. The objectives of President Eisenhower's "Atoms for Peace" speech (December 1953) seem to have been engulfed in a wave of enthusiasm to make the nuclear power program a sort of "nuclear and general scientific Marshall Plan." Objectives of the U.S. AEC, the U.S. Department of State, Euratom, and IAEA are not always compatible, and U.S. industry has been overlook to a point where there (its) enthusiasm is waning. The original objectives of President Eisenhower will (I believe) not be attained unless and until U.S. manufacturers and U.S. public utilities can see sound economic reasons for their aggressive participation in, and contributions to, the nuclear energy program.

U.S. public utilities are run by sound engineers and controlled by Public Service Commissions. Accordingly, public utilities will follow paths they know, understand, and consider promising for profit. Little progress in nuclear energy will be made until public utility officials can see possibilities for economic operations in the reasonably near future. Otherwise, their only incentives are prestige, training of personnel, or political protection. Overall, these incentives will result in few nuclear powerplants. Public utilities should not be expected to contribute stockholders' equity to buy prestige for the U.S.A. or to furnish the ammunition needed for the "cold war." This they would be doing if these were their only reasons for building nuclear powerplants costing much more than plants of conventional types.

I am convinced that the so-called nontechnical obstacles are serious deterrents to the nuclear power program. These obstacles may be sufficiently serious that the nuclear power program would be held up even if economically competitive operation could be assured. One could hardly blame public utilities for sticking to the conventional field—which of itself is sufficiently complex with Government control. Certainly utility management cannot make up their minds in questionable areas where Government organizations and scientific groups disagree.

Finally, the so-called 5-, 10-, 20-, and 30-year programs often appear incompatible. What may be best for the world over the long pull may not be best for a short-term program. Personally, I feel that the long-term programs will have a sounder basis if commercially economical nuclear power can be demonstrated—even under limited conditions—and then make progress from that point. I would favor hunting economic power with a rifle rather than with a shotgun or blunderbuss. For example, I question where aviation would be today if the decision had been made thirty years ago that they would not start commercial or military aviation until they had 600 M.P.H. or supersonic planes. Aviation started as a rather heavily subsidized industry, but even early in the game there were limited areas in which it was economically competitive with other forms of transportation.



In answer to the first question, we will confine our remarks to the High Temperature Gas-Cooled Reactors (HTGR's) since we are developing this class of reactors and can, therefore, project the economics of these plants with more assurance than for other types of atomic powerplants.

Based on the most realistic evaluation now possible, there are good prospects that HTGR atomic powerplants can be made economically competitive in high fuel cost areas in the U.S. within the five-year period, 1965–1970. The 40,000 Kw. prototype HTGR plant scheduled for completion in 1963 can be expected to produce the operating conditions which, when applied to larger plants, will result in economic nuclear power.

It is inherent in almost all reactors that large-size units will become more economic than small ones. This is particularly true in the case of the HTGR for it is in these large plants with their associated excellent neutron economy that reactivity can be conserved long enough to take full advantage of high burnup capability of the HTGR fuel element. Of course, the HTGR also benefits from the size effect on the unit capital costs in the larger plants as do other plants. The most likely choice of plant size for an early economically competitive plant during the period 1965–1970 is in the range of 150 to 250 Mw. The High Temperature Gas-Cooled Reactor stands high in the prospects for economic power because of its expected low fuel cycle costs and long fuel burnup. Its high temperature inherently suits it for modern steam turbine cycles using high steam pressures and temperatures.

It would be expected, of course, that the first locations where nuclear power will become economic are in parts of the United States or in foreign countries where the delivered cost for coal and oil are high.

Achievement of economic nuclear power, in my opinion, would be greatly slowed down if the AEC were to select and support only those reactor concepts which at this stage and time are the most developed.

The nuclear power field is still in its infancy and the determination as to which system or systems will prove truly economic must follow a great deal more research and development. The "best" reactor concepts should not be "selected" by the AEC but should evolve as a result of competition between reactor manufacturers for the business of the utility industry—the customer for power reactors. In this way, the selectivity inherent in the competitive process would be allowed to operate.

Achievement of economic nuclear power would be accelerated by increased and more comprehensive support of research and development.

Patent Policies.—It is impossible to demonstrate that the absence of incentive based on the anticipation of profits through patents has hindered scientific and technological advance in this field. However, it is our opinion that the incentives offered by the conventional patent system would provide additional stimulation to scientific and technological advance and would encourage the taking of risks by industry in the research and development area which might not otherwise be taken.

Third-Party Liability.—Lack of a solution to the third-party liability problem could prevent achieving the objectives stated by the President. While it appears that progress is being made in some parts of Europe toward a solution of this problem, the delay in arriving at a solution could unduly prolong achievement of the objectives, not only in Europe but in other parts of the world. Failure to achieve a reasonable solution to the third-party liability problem could, of course, seriously affect the economic aspects of nuclear power. There is a lack of commercial certainty which, we believe, is necessary to achieve the objectives within the framework of the free enterprise system.

Licensing and Regulations.—It is our opinion that industry is hampered in the speed and flexibility with which it is able to perform research and development in the atomic energy field. The regulations do not take sufficient account of the problems of an organization performing research in the field. Additionally, we feel that there is a need to increase the speed and certainty with which regulatory matters are handled.

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1. When, if in the foreseeable future, do you believe atomic powerplants can be economically competitive?

Atomic powerplants in the larger sizes can be economically competitive in the higher power cost areas of Europe during the period 1965–70. It is not expected that similar sized plants would be truly economic in most areas of the United States for another 5 years beyond that time. A number of nuclear and nonnuclear areas such as: excellent operating experience on reactors now under construction; major improvements in fuel element lifetime and simplified, lower cost materials of construction could all result in improvements in this future outlook.

Nonnuclear factors such as: continuing increases in the supply of conventional fuels together with a parallel reduction in the production of electricity from these sources; failure to proceed immediately with

future prototype-plant construction; lack of coordination between Government and industry as to the best method of supporting the industry; too limited a program for the development of the most efficient reactor types; could all have a negative effect and stretch out the date for economic power.

2. Although the nontechnical obstacles to the development of economically competitive atomic power can materially affect its achievement, I do not believe that they are so fundamental in nature as to cause reconsideration of the feasibility or desirability of reaching this objective.

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In brief our opinion on questions Nos. 1 and 2 on the January 26 questionnaire are as follows:

1. The table below is our best estimate of when nuclear power will first be competitive in the area indicated:

Size	1960-65		1965-70		1970-75	
	United States	Europe and other	United States	Europe and other	United States	Europe and other
Under 100 emw				X	X	
100-250 emw		X	X			
Above 250 emw		X	X			

Major factors which tend to accelerate or decelerate the time schedule noted in the above table are given below:

ACCELERATING FACTORS	DECELERATING FACTORS
Nuclear	
1. General availability of enriched fuel.	1. Any severe nuclear accident.
2. Increased throughput in fuel preparation and chemical processing plants.	
3. Low-cost, satisfactory zirconium and other improved fuel claddings.	
Non-Nuclear	
1. Increased Russian control of world oil deposits.	1. Any severe nuclear accident. party liability.
	2. Failure to prosecute vigorously the U.S. reactor development program.

2. In our opinion, we consider the third party liability problem to be of overriding importance with respect to the development and installation of nuclear power throughout the world. Indeed, present third party liability considerations severely retard nuclear power development today, and unless there is substantial improvement in

the present situation, any forecast such as noted under question 1 must honestly be classified as pure conjecture.

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Question. When can atomic power plants be economically competitive?

Answer. I don't believe an unqualified answer to this question makes sense. There are two subsidiary questions which need answering first: (1) When will coal and other fossil fuels become scarce enough to justify an all-out effort to achieve competitive nuclear power; and (2) At such time as coal becomes scarce, how much nuclear fuel will be available? I believe that until fossil fuels become scarce, nuclear power plants will remain special purpose plants, for instance, for submarines or remote base applications. When fossil fuels do become scarce, it will become more important, I believe, to consider the overall problem of conservation of our resources (high conversion ratios for fuel and high plan thermodynamic efficiency) than to find the irreducible minimum to plant capital costs, for example.

On the basis of the above considerations, which could be elaborated, I believe that nuclear power plants will, over a period of perhaps 50 years, become economically competitive over larger parts of the world. Development, construction, and operation of powerplants is necessary to gain experience on which to base future economy.

Question. Do nontechnical obstacles interfere in obtaining competitive power?

Answer. I believe that the restrictions mentioned are necessary in the present development stage of atomic energy where private industry is necessarily dependent upon military and other government developments for the carrying out of its technology. It seems reasonable to expect that these restrictions, particularly on security, will be lessened as industry is able to become self-sufficient in atomic energy.

It seems to me that the objective of economically competitive power requires that the U.S. Government with its laboratories, maintain a strong position; for instance, in the development of breeder reactors. For so long as this is true, some measure of the restrictions mentioned seem to me to be required.

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Question 1. "When, if in the foreseeable future, do you believe atomic power plants can be economically competitive? Please take into account: (a) time periods such as 1960–1965, 1965–1970, 1970–75, and after 1975; (b) plant sizes under 100 megawatts, between 100 and 250 megawatts, and larger than 250 megawatts; and (c) geographic locations such as the United States, Europe, Latin America, Asia, and Africa. In your response, please identify any nuclear or non-nuclear factors which you think might accelerate or slow down achievement of economic nuclear power."

It is believed that nuclear power plants of 100 EMW and larger can be shown to be economically competitive in limited areas of the U.S. (like the Northeast) about 1965–1970; it will be 1970–1975 before plants of less than 100 EMW can become economically competitive. The timing will be about the same in countries outside the U.S., or

perhaps five years later because of slow-moving programs—slow for reasons other than technological.

It is felt that a factor which would significantly accelerate the achievement of economic nuclear power is the greater use of the "free competition by private enterprise" concept in procuring materials and services for the many nuclear programs.

> Question 2. "In your opinion, are any of the so-called nontechnical obstacles, such as patent policies, third party liability, licensing and regulations, security restrictions, etc., so fundamental in nature as to cause reconsideration of the desirability or feasibility of achievement of the objectives stated by the President in his speech of December, 1953, namely, the development of economically competitive atomic power and the installation of a substantial nuclear-powered generating capacity throughout the world?"

The answer to this question as phrased is "No." On the other hand, however, there is no doubt that from time to time the nontechnical obstacles referred to will tend to slow progress. We do not see how they can be eliminated, but we do make the strong plea that policies pertaining to them be reconsidered frequently.

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I am sorry to have taken so long in replying. Some of this delay is due to the fact that with respect to the first set of questions, I do not feel that I am in a good position to comment either on the time that atomic powerplants will be economically competitive or what their size or location will be.

Concerning nontechnical obstacles, such as patent policies, liability, licensing, and regulations, etc., I have long felt that the most difficult and annoying problems reside primarily in the licensing and security areas, particularly in the latter. While the revisions in the Atomic Energy Law in 1954 were helpful, there are still numerous delays in obtaining up-to-date information which I think are going to continue to be a serious detriment to early realization of nuclear-powered generating capacity.

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CONSULTANTS AND ENGINEERS

1. When can atomic powerplants be economically competitive?

We believe that a few carefully selected and planned nuclear powerplants, probably of the boiling or pressurized water varieties, could be in economic operation in a few locations of the U.S. by 1969—give or take a year or two. Probably these first plants will be moderately large (150 to 250 emw) to balance size economy with restricted load and load factor requirements. Plants producing less than 100 emw may not become economic as early.

It is not likely that other than water types of reactor powerplants will be in economic operation until after 1969.

It is possible that in some locations in Europe and Latin America, nuclear powerplants in the small and medium sizes may become economic during the 1970's, and possibly in India—in countries industrializing rapidly in areas lacking conventional fuels or transportation for them. Many factors are important in the foreign location of U.S.-manufactured reactors which have led us to be pessimistic regarding economic installations abroad.

Unfortunately, during the last ten years the virtues and prospects of nuclear power have been oversold. This has led to (a) premature decisions to build large, expensive plants, and (b) the conduct of much varied and costly research. The expensive plants and costly research may themselves be important deterrents to further development of nuclear power, if not put in proper perspective, and if sufficient effort is not made to utilize fully the lessons learned and to be learned from the large commitments already made. To be most effective, such perspective and the lessons learned should be directed to and utilized by the utility industry. It is not clear that this is recognized by the existing national nuclear power policy.

The overall effort required to make nuclear power economic has proven to be very great. It is probable that a great deal more effort will be required, and it would thus appear prudent to concentrate this effort on a few selected reactor types, and to continue to urge that development effort and large-scale construction be transferred to the utility industry and its suppliers, which must ultimately make the decisions concerning economic worth.

The continued growth of AEC facilities, especially in component and system development and in pilot and prototype plant construction, is apt to continue the already unfortunate dominance of non-economic factors in directing the development of economic nuclear power, and a serious effort should be made to stop such growth.

2. Nontechnical Obstacles

In our opinion, none of the nontechnical obstacles, except perhaps national policies concerning national laboratories and reactor development, and unduly restrictive and time-consuming regulations, are so fundamental as to restrain the orderly development or nuclear power technology.

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Question 1

I would estimate that nuclear power will be competitive in the United States in the large stations greater than 250 MW for plants coming on the line between the period of 1965 and 1970. By competitive, I am assuming a definition of buss bar charges of approximately 7 mills/kwh. In the small plant size under 100 MW, I would place the competitive date somewhat after 1975; although in certain areas of high cost the plant should be competitive in the 1970–75 period.

In foreign locations based on mills/kwh you would expect nuclear power to be competitive substantially sooner than in the United States. In certain high fuel cost areas this would be the case but care should be taken in a mills/kwh analysis to fully account for the high conventional power charges. Load factors are many times in the 40–50% range which would have a greater detrimental effect on nuclear plant charges because of their higher capital cost.

An area which could either accelerate or slow down achievement of economic nuclear power is that of the fuel cycle charges. For example, it is generally recognized that the reprocessing charges have been set at a fictitiously low rate, related to the charges industry would have to make, for such service. An increase in these charges by perhaps a factor of two would have some effect in slowing the program down. The uranium 235 policies and the unknowns therein both from a production cost and long-term availability standpoint have always been of concern. Changes in the stated policy could have a very marked effect on the acceleration or slowing down of economic nuclear power.

One of the major technical developments which will affect economic nuclear power is that of fuel element technology. Indeed if such technology improves at a rate even nominally approaching the development to date, the above estimates of economic nuclear power would be improved considerably.

Question 2

The current government tax regulations on the writing off of research and development expenditures do not give these expenses a preferential tax treatment. A revision in the tax laws to permit these charges to be distributed in a more optimum manner (e.g., over several years or a specific year at the option of the company) would certainly be beneficial to the development of the nuclear power field. It is, of course, true that many of the research and development programs are being sponsored by various government contracts and these contracts are helping the development of nuclear power to a significant degree.

In some foreign operations third party liability has been a problem but in all likelihood as projects become economically competitive this situation will be resolved. Work should continue, however, towards finalizing this phase of nuclear business problems.

An unknown which could adversely affect the development of nuclear power is the possibility, in spite of all the safety precautions and conservative designs made to date, of a major nuclear accident in one of the powerplants now under construction. Such an accident would create a reevaluation of the safety approaches taken to date and would most certainly add additional costs to the nuclear program.

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Question 1

It seems to me to be probable that during the period of 1960–1965 it will be found that electric power requirements in certain cases can be met more economically with the use of nuclear power than with other energy sources. As a result it is to be expected that such plants will be designed and built, but because of the time required, they are not likely to become operative until the 1965–1970 period.

This opinion is based upon the simple assumption that costs will decrease as a result of the current nuclear research and development work and of the experience to be gained from current nuclear power projects.

It seems obvious that the nuclear powerplants which are to be built in preference to conventional plants will be in areas where the conventional plant would have to carry an extra burden of high transportation costs either for the fuel or for the power itself. It is, therefore, to be expected that the nuclear plants will be in areas where new power facilities are needed, but which are far from sources of fossil fuels or undeveloped hydropower.

Also, the bigger the power requirement, the greater would be the transportation burden for fossil fuels, and it therefore seems reasonable to expect that the nuclear plants will tend to be large. But because of the many factors involved in computing and comparing costs to meet a power requirement in some particular area, it is very difficult to predict whether the nuclear plants which are built will be above or below a certain size.

There are in my opinion two main reasons why nuclear power costs remain higher than conventional power. The first is the complexity of the technology. As a better understanding of the problems has been gained, they have been found to be quite a bit tougher than was generally realized when commitments were being made for the current generation of nuclear powerplants.

The second reason that costs remain high is simply that there has been little incentive to reduce them. Most of the research and development work has been in government-owned laboratories where the premiums for success are, in general, placed upon matters other than cost saving. This applies particularly to military projects, in which great emphasis has been placed upon water reactors. But it applies also to the development of other reactor concepts. For maximum ingenuity in finding inexpensive solutions to technical problems, a profit incentive is required. The gradual increase in the amount of nuclear research and development carried out in private facilities leads me to believe that cheaper methods for producing nuclear power are to be expected.

Question 2

The objectives stated by the President in his speech of December 23rd are just as desirable as ever, and I have no doubt as to their feasibility in the long run. The question is the time table. The nontechnical obstacles, such as those mentioned, deter but do not prevent the achievement of these objectives.

In particular, the patent policies tend to inhibit the development of private initiative, thus delaying cost reductions, as indicated above, and also weakening the competitive position of American manufacturers abroad. This tends to diminish the role of American private industry in achieving the President's objectives, but this may be offset by the relatively vigorous development of nuclear industry in other parts of the world. The licensing and regulations, and the security restrictions, also tend to deter the development of private initiative, but to a lesser extent.

The third party liability problem is in a special category because of its legal complexities, but experience in this country is already demonstrating that the problem can be solved so that it should only be a matter of time before it is also solved in other parts of the world.

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1. In the foreseeable future I believe that at least one atomic powerplant, the pressurized water type, can be economically competitive.

(*a*) During time period such as 1965–1970.

(*b*) Plant size larger than 250 megawatts.

(*c*) Geographic locations such as California and New England in the United States, parts of Europe, India, Taiwan, and Japan in Asia.

The chief nonatomic factor which might accelerate or slow down achievement of economic atomic power is the actual price of coal and oil in the future.

2. The so-called nontechnical obstacles, such as patent policies, third party liability, licensing and regulations, security restrictions, etc., are not so fundamental in nature as to cause reconsideration of the desirability or feasibility of the development of economically competitive atomic power and the installation of a substantial nuclear-powered generating capacity throughout the world. The passing of necessary legislation in various countries for third party liability is a most outstanding delaying factor.

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Question 1. When, if in the foreseeable future, do you believe atomic powerplants can be economically competitive?

Please take into account: (a) time periods such as 1960–1965, 1965–1970, 1970–1975, and after 1975; (b) plant sizes under 100 megawatts, between 100 and 250 megawatts, and larger than 250 megawatts; and (c) geographic locations such as the United States, Europe, Latin America, Asia, and Africa.

In your response, please identify any nuclear or non-nuclear factors which you think might accelerate or slow down achievement of economic nuclear power.

Answer: It is our opinion based upon present indicated progress in nuclear technology that, "atomic powerplants can be economically competitive" in the time periods listed below:

Area location	Plant size		
	Less than 100 MWe	100 to 250 MWe	Larger than 250 MWe
United States	After 1970	1965–70 [1]	1970–75.
Europe-Great Britain	1965–70 [2]	1965–70 [2]	1970–75.
Latin America	1970–75	1970–75	After 1975.
Asia (non-Soviet)	1970–75	1970–75	Do.
Africa	1970–75	After 1975	Do.

[1] Plants constructed in the 1960–65–70 periods would not be economically competitive until 1970–75; however, a second core in reactors such as Dresden, Indian Point, Yankee, etc., appear to be likely prospects to achieve a competitive position in the 1965–70 period provided "excess" capital costs can be written off.

[2] It is possible for the existing plants and those underway in Britain and Italy to achieve a competitive position in the 1965–70 period by incorporating expected economies in fuel cycles as they are developed.

The higher capital costs associated with nuclear plants would indicate the larger size plants, 300 MWe and larger, with their prospects of lower unit costs per KWe, have the best chance of becoming competitive. However, this situation may not materialize too soon time wise because of the large capital outlay required for such plants and

also because only a few electric systems (United States, Europe-Great Britain) can accommodate plants of that size.

The major obstacle standing in the way of attaining economic nuclear power is that of achieving a fuel cost sufficiently lower than conventional fuel costs to offset the inherently higher capital costs of nuclear plants.

It will require a concerted effort on the part of both private industry and the A.E.C. to reduce fuel costs and capital costs of nuclear plants to the level of where the overall costs are competitive. The efforts must cover the whole broad area of research and development, experimental plants, prototype plants and full scale plants.

Question 2. In your opinion, are any of the so-called nontechnical obstacles, such as patent policies, third party liability, licensing and regulations, security restrictions, etc., so fundamental in nature as to cause reconsideration of the desirability or feasibility of achievement of the objectives stated by the President in his speech of December 1953, namely, the development of economically competitive atomic power and the installation of a substantial nuclear-powered generating capacity throughout the world?

Answer: It is our opinion the so-called nontechnical obstacles listed above are not in themselves a major deterrent to achieving competitive nuclear power; however, it would be of assistance, cost wise, in attaining that goal if (1) third party liability costs could be reduced—now in the order of ten times the cash outlay for comparable conventional plants, (2) licensing and regulatory procedures could be clarified and simplified, hence less costly, and (3) the patent situation could be liberalized so as to encourage private enterprise with developments leading to lower costs.

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1. I expect nuclear power to become economically competitive with conventional power in high-fuel-cost areas of the United States in 1965–70, in large-size plants. I think it will be a long time before nuclear fuels will be economic in powerplants with capacity under 100 megawatts in the United States.

2. No.

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1. My opinion is that nuclear stations of 150 MW and greater size will be offered by U.S. manufacturers to clients in Europe at $250/KW installed, and with net fuelling costs of 2.0 mills/KWH within the next two years. Such a station would likely compete with a conventional oil burning station in Europe if the delivered cost of oil to the utility was 44¢/10^6 BTU ($18.00/Tonne). I have assumed the fixed charges would be 14% per year, the conventional station would cost $150/KW; O & M costs for the nuclear station would be 1.3 mills/KWH, and for the conventional station would be 1.0 mills per KWH. Annual net generation in each case was taken at 1 billion KWH.

2. Quite obviously, there are inconveniences and must be dealt with. Third party liability is perhaps the stickiest problem and its resolution will entail international action. However, if nuclear power can be shown to be economically attractive I have no doubt the third party liability problem will be speedily resolved.

I think the question simplifies to too great an extent the objectives of the December 8, 1953, speech. However, assuming for the moment that the question properly states those objectives, I see no nontechnical reason so fundamental in nature as to cause reconsideration of the feasibility or desirability of achievement of them.

As to the desirability of installing a substantial nuclear power agency throughout the world, I would say this:

Nuclear-generated electricity differs in no way from electricity generated by any other means. A user should therefore pay no more for nuclear electricity than for any other electricity. The choice of generating station for any particular situation should not be made without full consideration of the economic costs * * *.

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STAFF NOTE.—The following material has been excerpted from "Towards A New Energy Pattern in Europe," Report of the Energy Advisory Commission of the OEEC, made available to the Review by the courtesy of OEEC.

VI

PROSPECTIVE DEVELOPMENTS IN THE FIELD OF NUCLEAR ENERGY

99. Since the Hartley Commission reported, a great deal of thought has been devoted both to the technical and to the economic problems of nuclear energy. Experience has been gained by the United Kingdom Atomic Energy Authority both from the actual operation of the first dual purpose stations at Calder Hall and from the designing and constructing of the new units now being built at other places. At the same time designs and developments in the United States, in France and other European countries have provided more information for the assessment of the competitive position of nuclear energy during the next ten years. Construction programmes in a number of countries have reached the point at which the order of magnitude of the possible electricity generation in nuclear plants by 1965 can be very approximately guessed. The scale of possible generation in 1975 remains substantially uncertain.

100. We must begin by emphasizing again, as did the Hartley Commission, that neither by 1965 nor on the most optimistic assumptions by 1975 will nuclear energy represent more than a relatively small contribution to Western Europe's total supplies of energy: at most the supply from this source cannot exceed 10 per cent of the probable total fuel consumption of Western Europe in 1975, and it is more likely to represent a contribution of the order of 5 per cent.

101. This perspective is necessary to any responsible discussion of the problems created by these new potential sources of energy. Greatly important as they are, it would be disastrous if the uncertainties consequent upon their discovery were to impede the development of the traditional sources of energy, which for a very long time ahead will necessarily remain our chief support.

102. Nonetheless the development of nuclear energy and capital investment for its future supply has become so important a part of the energy programme of many European countries that we have devoted much attention to the assessment of its economic prospects. In the immediate future most countries are quite consciously buying expe-

rience in this new field which may later be valuable to them in meeting their own requirements and possibly in developing new export markets. In the long run the rate of expansion of nuclear energy is bound to be determined increasingly by more strictly economic considerations. We have therefore thought it right to examine and present such evidence as is available in this very uncertain field.

103. Nuclear energy, though fuel costs are by no means negligible, is comparable with hydro-power in that it represents a means of reducing subsequent fuel costs by the immediate investment of a substantial volume of capital. The profitability of doing this turns on the rate of return on capital which may be appropriate in a particular country. If the necessary rate of return on capital is sufficiently low, if the volume of additional capital required is not great, and if the saving on fuel costs is, on the other hand, considerable, the capital investment may be profitable.

104. The application of these obvious principles to the problems of nuclear energy is surrounded by difficulties. The capital cost of a nuclear plant is only by degrees beginning to be known. The construction of the earliest stations has involved heavy design and development costs as well as the solution of abnormal constructional problems. Successive generations of new stations will almost certainly show progressive reductions as experience accumulates. Until more experience has been gathered, however, both of actual, as distinct from estimated, costs and of the possible reductions of costs in subsequent stations, it is difficult to judge with any certainly just how soon nuclear plants can be expected to be fully competitive. Equally the life of a nuclear plant must remain a matter of guesswork until the first generation of plants has completed its life, and even longer if technical progress contributes to longevity. Moreover the future relative price of nuclear fuels is substantially uncertain. In all these matters the uncertainty regarding nuclear stations has to be contrasted with the firm basis of experience that exists regarding all the characteristics of thermal stations. Finally, there remain to be solved many of the problems of the best relation of nuclear stations to a complete system of electricity supply arising from the high load factor at which nuclear plants must be operated.

105. In Table 27 below we have attempted to present the best evidence available to us regarding the costs of generating a unit of electricity in nuclear plants at the stage of development that may be reached in plants now being designed, and we have compared these estimates of cost with the costs in coal-fired plants at the same stage of development and which might be constructed during the same period. Our estimates should be regarded as referring to stations which might potentially be built to come into commission between 1965 and 1975.

106. The lower assumptions that we have made regarding the possible capital costs of nuclear stations are believed to be considerably below the full costs of the present generation of stations, if proper allow-

TABLE 27. ESTIMATED FUTURE COSTS OF GENERATING ELECTRICITY IN NUCLEAR AND THERMAL PLANTS WITH DIFFERENT RATES OF INTEREST, DIFFERENT CAPITAL COSTS AND DIFFERENT FUEL COSTS

In mills per kWh.

	NUCLEAR PLANTS *20 year life: 75% load factor*												COAL-FIRED PLANTS *28 year life: 75% load factor*											
	NATURAL URANIUM PLANTS						ENRICHED URANIUM PLANTS						LOW FUEL COST						HIGH FUEL COST					
Specific capital costs[1]	$250/kW_e			$350/kW_e			$225/kW_e			$300/kW_e			$125/kW_e			$155/kW_e			$125/kW_e			$155/kW_e		
Interest[2] and amortization ..	8%	12%	16%	8%	12%	16%	8%	12%	16%	8%	12%	16%	6.7%	10%	13.4%	6.7%	10%	13.4%	6.7%	10%	13.4%	6.7%	10%	13.4%
Financial charges	3.0	4.6	6.1	4.3	6.4	8.5	2.7	4.1	5.5	3.7	5.5	7.3	1.3	1.9	2.6	1.6	2.4	3.2	1.3	1.9	2.6	1.6	2.4	3.2
Fuel costs[3]	2.6	2.9	3.2	2.6	2.9	3.2	3.4	3.7	4.0	3.4	3.7	4.0	4.3	4.3	4.3	4.3	4.3	4.3	6.5	6.5	6.5	6.5	6.5	6.5
Operating costs[4] .	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Insurance	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	—	—	—	—	—	—	—	—	—	—	—	—
Total	6.6	8.5	10.3	7.9	10.3	12.7	7.1	8.8	10.5	8.1	10.2	12.3	6.3	6.9	7.6	6.6	7.4	8.2	8.5	9.1	9.8	8.8	9.6	10.4

1. The above values are believed to be appropriate for both nuclear and conventional thermal plants of about 500 MW.
2. Interest and amortization at 8% represents about 5% interest plus amortization over 20 years; the higher charges represent a probable upper limit of double such charges; for coal stations the charge of 6.7% represents about 5% interest and amortization over 28 years and the higher rate again represents an upper limit of double that charge. In all cases the financial charges make some provision for taxes and duties.
3. As mentioned in paragraph 109, these estimates are largely based on the working hypotheses set out in " The Industrial Challenge of Nuclear Energy III ", Part I, Annex I. Fuel costs per kWh include an allowance for interest on initial fuel charge ; for natural uranium, the price for the metal has been taken as $ 40/kg and the manufacturing cost of fuel elements has been taken as $ 16/kg. High fuel costs for coal-fired plant represent fuel costs 50 % above the cost at a site near the coal mine.
4. Based on operating and maintenance costs of about $5.25/kW/year for nuclear plants and about $4.50/kW/year for conventional plant.

ance is made for design and development costs which constructors must ultimately hope to recover. We believe them, however, to be within the limits of possibility of the period 1965-1975.

107. We have presented these estimates of cost in terms of various alternative assumptions of the appropriate rate of interest. The assumption of an interest rate of about 5 per cent and a twenty-year amortization period correspond to the 8 per cent total of financial charges that we have set out as our minimum. This represents the level of financial charges that the United Kingdom Atomic Energy Authority has considered appropriate to its own situation. We have set out alternative hypotheses on the basis of financial charges of 12 per cent and 16 per cent as representing the possibly appropriate charges in countries where rates of interest are considerably higher than in the United Kingdom. The current developments in Italy, for example, are based upon financial charges, including amortization, amounting to 14 per cent. In all cases the financial charges make some provision for taxes and duties.

108. We have assumed a life of twenty years for nuclear plants as compared with a life of twenty-eight years for the coal-fired plants with which we make comparison. We believe that this is a not unreasonable assumption for the life of the next generation of nuclear stations; if the life can be assumed to be nearer to that of a coal-fired station, the competitive position of the nuclear station would be improved. We have assumed that both the nuclear plants and the coal-fired plants with which we make comparison are similarly operated on a 75 per cent load factor so that the choice between them is made on an identical basis. If the load factor were higher the competitive position of the nuclear plant, with its heavier capital charges, would be improved. Where a load factor as high as 75 per cent cannot be assumed the nuclear plant would, for the same reasons, compete less favourably.

109. The fuel costs and other operating costs assumed represent the best estimates that are available to us and are based on studies made by the European Nuclear Energy Agency[1]. We make no claims for great exactitude in a field in which that is for the moment impossible. In particular we attach no significance to the slight differences that have emerged between our estimates of the costs in natural uranium and enriched uranium plants respectively. The margins of uncertainty are too great for us to wish to pronounce on this very debatable issue.

110. We content ourselves with emphasizing certain fundamental issues which seem to us to emerge from the table. At the state of development likely to be reached during the next few years, electricity generated in nuclear plants seems unlikely to be competitive on a strictly economic basis unless it may be simultaneously assumed that the appropriate rate of interest is 5 per cent or less, that the nuclear plant is constructed in a country in which construction costs for this very elaborate

1. The Industrial Challenge of Nuclear Energy III, O.E.E.C., October 1959. Part 1, Annex I.

plant are relatively low, and that the alternative costs of traditional fuels are relatively higher than they normally are in the neighbourhood of coal mines. With interest rates which, with amortization, involve total financial charges as high as 12 per cent, the cost of electricity generated in a nuclear plant at the state of development of the near future seems likely to be higher than the comparable cost in a thermal plant, except where fuel costs for the latter are abnormally high. With total financial charges as high as 16 per cent, the cost of nuclear energy seems likely to be considerably higher than that of a coal-fired station on any reasonable assumptions as to fuel and construction costs.

111. We very fully realise the limitations of the evidence that we have considered. There may, moreover, be exceptional cases where hydro-power is already exploited to the economic limit or other resources are becoming exhausted in which nuclear energy may quickly become competitive. In particular we should make it clear that we expect both costs of construction and fuel costs in nuclear plants to decline more rapidly than those of thermal stations which have already reached a high state of development, so that by 1975 new construction may be much more nearly competitive. During the interval covering 1965-1975 we think that it is not improbable that the volume of construction will be limited and reflect more closely the economic competitiveness of this new form of energy than it does immediately while most nations are seeking to acquire relevant and valuable experience.

112. If the strictly economic competitiveness of nuclear energy is, as we believe it to be, very sensitive to the rate of interest adopted, it becomes exceedingly important that the rates of interest used in any calculations should be those that are genuinely appropriate to the situation. We think that this can best be considered in terms of the returns obtainable on those investments in any nation which must be postponed if investment is made in nuclear plant. We do not think it appropriate that profitability should be judged in terms of the preferential rate at which a government may be able to borrow at fixed interest, if it is implied that the inevitable risks and uncertainties of the development of nuclear plants are wholly borne by the tax-payer and are excluded from the calculation of cost. Such a procedure may be legitimate in a limited operation, if it is judged to be in the national interest to acquire valuable experience. Great caution should, in our view, be exercised in extending a similar procedure on a large scale, unless it can be shown that other countervailing advantages are valued so highly as to justify it.

113. The present construction programmes are shown in Annex 5. The total capacity already in operation or under construction amounts to about 2.4 GW_e. A further 1.6 GW_e is at the stage of negotiation of contracts. Another 4 GW_e have reached an advanced stage of planning. It is not easy to judge what proportion of this capacity will be actually in operation before the end of 1965. Having regard to the difficulties of construction and of the delays that have been generally

experienced, we think that the capacity available by the end of 1965 is likely to be of the order of 5-7 GW_e. For the higher figure to be achieved it will be necessary to start construction of about 4 GW_e during the next two years.

114. We find ourselves unable to present anything but a wide range of possibilities for 1975. Different members of the commission hold widely different views as to what is possible and probable. As a lower limit we think that nuclear capacity is likely to be not less that 10 GW_e by 1975. Such a figure would necessarily imply that after the completion of the stations which, on our lower estimate for that year, are likely to be completed by 1965 further construction in Europe as a whole (including the United Kingdom) would average, during the decade 1965 to 1975, the equivalent of one 500 MW_e station per year. This would assume that during that period, while its competitive position was being established, nuclear development continued on a research rather than a commercial scale. On that basis, nuclear plants would represent less than 4 per cent of the total electrical generating capacity added during the period.

115. As an upper limit to what seems probable (though it does not represent the limit of possibility) we think that it is proper to take 35 GW_e. This might represent the installed nuclear capacity by the end of 1975 if nuclear energy were competitive from the late 1960, and the greater part of new additions to base-load capacity took the form of nuclear plant from that time onwards.

116. Thus we estimate that the installed nuclear capacity for electricity production is likely to lie within the following limits:

1965: 5— 7 GW_e
1975: 10—35 GW_e

117. Assuming about 6 500 utilisation hours per year in 1965 and about 6 000 hours in 1975, with load factors of approximately 75 per cent and 70 per cent respectively, the electricity production should be:

1965: 33— 46 TWh
1975: 60—210 TWh

With a combined nuclear power plant efficiency of about 28 per cent in 1965 and of about 31 per cent in 1975, nuclear heat input for power production would thus be as shown in Table 28 below.

118. In addition some allowance must be made for the direct utilisation of nuclear heat. Only Sweden has as yet produced a programme for this. We cannot do more than include a notional provision of 5 million tons of coal equivalent for the O.E.E.C. area in 1975.

119. Only a small part of this energy will, however, be met from indigenous production of nuclear fuels. The nuclear energy that may in fact be derived from indigenous fuels is uncertain within even very wide limits; it may perhaps amount to about one-sixth of the whole in

TABLE 28. ESTIMATED CONTRIBUTIONS OF NUCLEAR ENERGY TO PRIMARY FUEL CONSUMPTION IN THE O.E.E.C. AREA

Million tons of coal equivalent.

	1965	1975
Input for power production	15-20	25-85
Nuclear heat supply	—	5
Total primary nuclear energy	15-20	30-90

1965 and possibly a quarter in 1975. The remainder will come from nuclear fuels imported from the United States, Canada or overseas territories either as natural uranium ore and metal, or as enriched uranium or fuel elements. We shall consider the problems implied by the import of nuclear fuels at a later point in our report.

120. In the meanwhile it seems to us important to attempt to assess the possible cost of the encouragement of nuclear energy. We may approach the problem from two alternative angles: firstly, we may attempt to see how much the current running cost of energy in any year is increased by substituting electricity generated in nuclear stations for electricity generated in thermal stations of comparable date; secondly, we may attempt to measure the full additional capital investment cost resulting from the substitution of nuclear for thermal stations. We should stress that any such calculations can only establish rough orders of magnitude and that the additional costs will vary according to local circumstances.

121. The costs of generating electricity in a nuclear station of the types now being constructed may be estimated to be about 2 to 5 mills per kWh higher than in a comparable thermal station, the difference depending on the appropriate rate of interest in a particular country, on construction costs in a particular country, and on the delivered costs of alternative fuels in a particular country. For a very rough calculation it would not be unrealistic to take an average figure of a difference of 2.5 mills in 1965. By 1975 it may be realistic to assume a difference of the order of 1 mill; if all goes well, the difference on new plant then being constructed may be negligible.

122. It has been estimated (paragraph 117) that in 1965 some 35-45 TWh may be generated in nuclear plants and in 1975 some 60-210 TWh, depending on development policy after the pilot stage. On the basis of an addition to cost of 2.5 mills per kWh in 1965 and 1 mill per kWh in 1975 the additional cost would be: 1965, $85-115 million; 1975, $60-210 million.

123. These figures may be related to the estimated gross national products of all Member countries of the same years:

TABLE 29. APPROXIMATE ADDITIONAL COST OF NUCLEAR ENERGY AS A PROPORTION OF ESTIMATED GROSS NATIONAL PRODUCT IN THE O.E.E.C. AREA

At 1955 prices.

	1965	1975
Approximate additional cost of nuclear energy *$billion*	0.09-0.12	0.06-0.21
Estimate of gross national product ..... *$billion*	300	400
Additional cost as % of G.N.P.	0.03-0.04%	0.02-0.05%

124. The additional investment cost consequent upon the development of nuclear energy has been estimated to be about $2 billion during 1955-1965 and $1 to $5 billion during 1965-1975, according to whether a moderate or a rapid policy of nuclear development is followed[1]. These figures may be compared with the total fixed capital investment estimated for the two decades:

TABLE 30. APPROXIMATE ADDITIONAL CAPITAL COST OF NUCLEAR ENERGY AS A PROPORTION OF ESTIMATED GROSS FIXED INVESTMENT IN THE O.E.E.C. AREA

At 1955 prices.

10 YEAR PERIOD	1955-1965	1965-1975
Approximate additional capital cost of nuclear energy ..... *$billion*	2	1-5
Estimated gross fixed investment ..... *$billion*	475	625
Additional cost as % of gross fixed investment	0.4%	0.2%-0.8%
Estimated total fixed investment in energy... *$billion*	58	76-79
Additional cost as % of fixed investment in energy ..	3.4%	1.3%-6.3%

125. These figures, and particularly those relating additional nuclear energy costs to gross national product, need to be considered against a background of an annual increase of gross national product of the order of 3 per cent. The burden, though by no means negligible, clearly cannot be regarded as wholly insupportable, particularly when account is taken not only of the prospect of creating an important new source of future supplies from nuclear energy, but also of the security aspect in making it possible to reduce temporarily the volume of imports of energy.

1. See paragraph 161.

TEXT OF LETTER FROM COMMISSIONER PAUL DE GROOTE, EURATOM, TO ROBERT McKINNEY

Pursuant to our conversations of January last and to keep the promises which I made to you, I am sending you herewith two copies, in English, of the memorandum containing a first evaluation of the Community's energy prospects.

We are still waiting to receive the complete statistics for 1959 in order to carry out any revision which may be necessary on certain figures. At the present time, however, I am working on the basis of the data contained in the attached document, which have been compared with the information obtained by my colleagues in the other communities.

(STAFF NOTE.—The following report has been circulated, and comments have been received by the authors. At the time of this printing, however, the comments are not available.)

EUROPEAN ATOMIC ENERGY COMMUNITY

Brussels, 3 May 1960
Orig. French

E U R A T O M

The Commission

OUTLOOK FOR THE DEVELOPMENT OF NUCLEAR ENERGY

Introduction

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II. Forecasts of Electricity Requirements
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I N T R O D U C T I O N

1. The present study aims at giving a preliminary assessment of the prospects for nuclear energy and the scale on which it will be required. This study is drawn up along lines which are still comparatively schematic so that many points will have to be expanded and clarified in the future.

The facts and figures contained in this study will make it possible at a later stage to draw up a first target programme as referred to in Article 40 of the Treaty.

The study will be revised in line with the new facts as they are brought to light. This revision will take particular account of the comments formulated by the Interexecutive Working Group on Energy Problems when it examined this study, which was submitted to it by the Commission.

A comparison between the forecasts published below ans those established for a bigger Europe and for a different period raises a number of difficult questions. A first analysis, however, does not reveal any significantly divergent conclusions.

2. The prospects have been examined over a period of twenty years, i.e., up to 1980, which appears quite adequate to develop nuclear technology to a stage in which it can be exploited economically and to enable the most recent conventional power plants to benefit from regular amortization periods.

It seems probable that during this period, nuclear energy will be used mainly to produce electricity. In the present status of the study, no forecasts have been made for its possible exploitation for district or industrial heating or naval propulsion, and only electrical energy production has been taken into consideration.

3. At the present moment, the Community does not possess a single actual nuclear power plant. As at least three years are needed for construction, plus a further year for commissioning, a plant of this kind does not normally come into economic operation until the fifth

year from the start of building. We shall thus have to wait until 1964 at least before obtaining any data on industrial operation which will throw some light on the conditions in which nuclear power may be brought into play.

The study is therefore based on the assumption that, up to 1965, and taking into account the contribution of nuclear plants already in the planning stage, increases in production will be covered by conventional power plants. Nor is it assumed that existing or modernized plants working on conventional fossil fuels will be replaced by nuclear power plants during the remainder of the period in question.

4. It is acknowledged, in principle, that the contribution of nuclear energy made in future to the electrical energy production will depend on one basic condition, i.e., the competitive nature of this new source of energy as against the other available sources.

5. This memorandum is drawn up on the basis of moderate electricity demand forecasts and, as is apparent from the foregoing, on relatively minimum hypotheses for the development of nuclear energy. This seems to be a reasonable attitude to adopt, since the advent of nuclear energy is not just around the corner. We have, therefore, a period of some years at our disposal, which we had best use to observe trends, in the nuclear and power field, and to revise and set up progressively the forecasts for power requirements and for the investments which will be necessary to meet them.

6. For purposes of interpreting the results of this study, it was found advisable to simplify matters by giving a single figure rather than to take a maximum and a minimum hypothesis and thus suggest, wrongly, that the truth lays somewhere between these two limits.

PART I

ENERGY NEEDS

I. Rough Estimate of Overall Power Requirements

7. This estimate is arrived at by extrapolating up to 1980 the function which expresses the relationship between energy consumption and general economic activity and which at the same time makes due allowance for the intrinsic and regular development of energy consumption as a function of time.

To begin with, the probable trend of general economic activity must be assessed. On the basis of the studies which have been carried out, this can be expressed in annual rates of growth in industrial production.

For the Euratom countries taken as a whole the following provisional rates have been selected. They are commented on in Annex I.

Probable Development of General Economic Activity

Period	Annual rate of growth of industrial production (in %)
1955 - 1960	5.5
1960 - 1970	5
1970 - 1980	4

The comparisons made by the Interexecutive Working Group on Energy Problems give good reason to believe that these figures are not exaggerated and that they may be adopted as a minimum until new studies make it possible to form a more precise opinion on the matter.

8. By applying a method described in detail in Annex II, the following forecasts were arrived at for primary energy requirements :

Forecasts for primary energy requirements

	in 10^6 TCE	index numbers
1955	398	100
1960	468	118
1965	540	136
1970	624	157
1975	695	175
1980	774	195

It should be pointed out that this energy will be consumed, either in its original form or after transformation into secondary energy, particularly electricity.

9. The forecasts for electricity consumption are contained in the following paragraph. In comparing them with the forecasts established for primary energy requirements, an attempt can be made to assess the prospects for non-electrical energy demands.

As there is no satisfactory method of forecasting their trend, the simple calculation of the difference between the two estimates provides an extremely rough indication on the basis of which they would increase by about 100 million tons of coal equivalent between 1960 and 1980. This increase is not so great that it cannot be covered by resorting to conventional sources, nor will it mean an abnormal drain on the reserves.

This observation only tends to suggest that, in all probability, nuclear energy will not be called upon, during the period in question, to fill in any gaps caused by non-electrical energy shortages.

II. Forecasts of Electricity Requirements

10. The factors on which these estimates are based are detailed in Annex III.

It will be recalled that the annual rate of increase in electricity demands was considered as being dependent :

- partly on a coefficient proportional to the rate of expansion of industrial production,
- partly on a constant rate expressing the regular tendency to extend the field of application of electricity.

The trend forecast is given in the following table :

Forecast of electricity demand

	In 10^9 kWh	Conversion into 10^6 TCE	Index Numbers	Annual rate of growth during the preceding period (%)
1955	185	97	100	-
1960	264	124	143	7.2
1965	370	155	200	6.8
1970	518	202	280	6.8
1975	701	259	379	6.1
1980	950	332	514	6.1

11. Various methods can be employed to establish forecasts of this nature and estimates have been drawn up by several different bodies. The results obtained are discussed in Annex IV.

12. Forecasts of electricity consumption may be compared with the forecasts of primary energy demands in the following manner :

Share of forecasts for electricity in the primary power forecasts

	Total power in 10^6 TCE	Electrical energy in 10^6 TCE	% electricity in total energy
1955	398	97	24.4
1960	468	124	26.5
1965	540	155	28.7
1970	624	202	32.4
1975	695	259	37.3
1980	774	332	42.9

These percentages may appear very high, especially for the end of the period, when compared with the American figures, for example. A detailed examination of this question will be made later.

As a first approximation, however, this observation would not seem to be enough to cast any doubt on the validity of the electricity forecasts. The comparatively large importance of electricity in Western Europe may be in fact explained by the differences which exist between the power economies of the six Euratom countries on the one hand and that of the United States on the other. In particular, this importance may arise from :

- lower general per capita power consumption in Europe than in the United States,
- much higher road and air transport density in the United States,
- relatively more advanced development of American agricultural mechanization,
- the large part played by natural gas in the United States to cover energy requirements.

III. The electricity demand which can be met from nuclear sources

13. The preference given to the transformation into electricity of certain primary energy sources is so marked that in some cases these sources are no longer used at all if the transformation into electricity does not take place. The most important of these sources are :

- lignite
- blast furnace gas
- refuse coal
- hydroelectric and geothermic power
- certain important natural gas deposits.

It is hardly reasonable to assume that, in the next twenty years, nuclear electricity will be in a position to replace the power which is derived at relatively low cost from these "privileged" sources.

Annex V comments the factors on which the forecasts for the development of electricity, relating to these particular sectors, are based. The next table gives these forecasts.

(see table on next page)

Forecasts for electricity production from lignite, blast furnace gas, refuse coal, hydroelectric and geothermic power, and natural gas, expressed in 10^9 kWh

	lignite (brown coal) power plants	blast furnace gas power plants	refuse coal power plants	hydroelectric and geothermic power plants	natural gas power plants	TOTAL (to the nearest whole number)
1955	19.2	7.9	23.2	70.2	1.4	122
1960	32.5	11.6	42.0	85.7	4.1	176
1965	49.9	14.0	58.0	105.0	9.7	237
1970	56.0	16.5	74.0	120.0	13.5	280
1975	62.1	19.0	91.0	135.0	17.9	325
1980	68.0	22.0	105.0	150.0	25.0	370

As is explained in Annex V, systematic use has been made of forecasts emanating from one and the same source, i.e. the First Report on a Coordinated Energy Policy published in April 1959 by the Mixed Committee of the Council of Ministers and the High Authority. Compared with other sources, these forecasts seem, on the whole, somewhat generous. However, they have been adopted, for purposes of homogeneity, and also to be reasonably conservative in making nuclear forecasts.

14. Assuming that nuclear energy will get no share of the energy produced from these privileged sources, within the next twenty years, the following table can be said to show the forecasts with respect to the nuclear field :

Forecasts of electricity requirements, more directly linked up with nuclear energy possibilities expressed in 10^9 kWh

	Electricity demand	Electricity produced from privileged sources	Proportion to be met from other sources
1955	185	122	63
1960	264	176	88
1965	370	237	133
1970	518	280	238
1975	701	325	376
1980	950	370	580

Forecasts of the same requirements, expressed in 10^6 TCE

	Electricity demand	Electricity produced from privileged sources	Proportion to be met from other sources
1955	97	64	33
1960	124	83	41
1965	155	100	55
1970	202	109	93
1975	259	120	139
1980	332	129	203

It is interesting to note the considerable increase, in the course of the period under consideration, in the proportion of the electricity demand not covered by privileged sources. According to the figures given in the last table but one, this share increases more than sixfold between 1960 and 1980.

This fact gives an initial idea both of the extent of the problems which will arise in the future with regard to electricity production and of the scope which will be open to nuclear power in this connection.

15. That proportion of electricity production accessible to nuclear energy and detailed in the above estimates must be restricted to make allowance for the hypothesis, which is, a priori, probably correct, according to which the amount of electricity produced by conventional plants will not drop, during the twenty-year period under consideration, below the level attained in 1965, account being taken of the fact that, by that time, nuclear power plants will have been built with an installed capacity of some 2,000 MWe.

It appeared reasonable to consider that :

- increases in electricity production from 1955 to 1960 will have been achieved entirely with the conventional plants;
- the installed power of the conventional plants in 1960 will not be reduced between 1960 and 1980;

- increases in electricity production between 1960 and 1965 will be achieved by nuclear power only to a level of 14 billion kWh, representing some 5.9 million TCE. The balance will be covered by increased production on the part of the conventional plants;
- production increases after 1965 will be accessible to nuclear power plants.

Applying these hypotheses to the figures given in the preceding tables, we obtain the following results :

Forecasts of electricity demands which could be met by nuclear power

	In 10^9 kWh	Conversion to 10^6 TCE
1965	14	6
1970	119	46
1975	257	95
1980	461	161

These are the figures, calculated with due caution and as a first approximation, representing the electricity production which can be regarded as accessible to nuclear power plants. The figure for 1980 amounts to almost double the total quantity of electricity produced in 1959.

An attempt should be made now to estimate the conditions in which these possibilities might be fulfilled.

PART II

THE EXTENT OF NUCLEAR POWER PLANTS REQUIRED

I. The Conditions for the Use of Nuclear Power

16. Sooner or later, nuclear energy will gradually be able to :

- supplement conventional sources of power,
- supersede classical power plants as a result of the general and permanent economic advantages, certainly to be derived from such substitution,
- facilitate further expansion and act as a stimulant to the economy in general as soon as it has become a particularly cheap source of electricity.

In the 20-year period lasting from now until 1980, however, there are two main aspects to the problem :

- the use of nuclear energy as a necessary alternative in the event of failure on the part of other sources to cope with demands or if requirements can only be met by stepping up fuel imports excessively,
- the exploitation of nuclear energy on the basis of the economic advantages offered and mainly of competitive production costs.

II. Dependence on Fossil Fuel Imports

17. It may be assumed that net Community fossil fuel imports will amount, in 1960, to around 125×10^6 TCE. This will represent about 27 % of the total power consumption forecast for the year 1960. It is particularly difficult to form an idea of the development of fuel imports over the next twenty years.

But we can, in any case, estimate that in 1980 :

- if the increase in overall power demands had to be met by fossil fuel imports alone (apart from the anticipated expansion of the privileged sources previously defined) with no contribution from nuclear sources beyond the approximate 2,000 MWe laid down for 1965, the Community would become dependent on imports for around 49 % of its power requirements (i.e. 379×10^6 TCE),

- if the entire electricity production accessible to nuclear power were in fact covered by nuclear power plants, dependence on imports would drop from about 49 % to about 28 % of total consumption (i.e., from 379 to 218 x 10^6 TCE).

The contraints of dependence on imports outlined above could exert a variety of effects on the economies of the countries concerned, primarily :

- upset balance of payments,
- insecurity, both in volume and price, of fuel supplies,
- difficulties in case it became impossible to find sources of supply.

It emerges from this that the advantages accruing from the exploitation of nuclear power will be by no means negligible. Anticipating the findings of the present study, we can estimate that the nuclear plants scheduled for 1980 might reduce fuel imports from 379 x 10^6 TCE to around 276 x 10^6 TCE.

In percentage of total primary energy the imports would thus drop from around 49 % to about 36 %.

This reduction of over one quarter would involve, at the price of 13.5 $ per TCE, a foreign exchange saving of 1.4 x 10^9 $, from which we should, of course, deduct purchases to be made outside the Community to guarantee the operation of certain types of reactors.

It is, however, probable that the material possibilities with regard to the supply of fossil fuels will be adequate during the next twenty-years and that there is only a very slight risk that supply of conventional fuels required by the Euratom countries will fall below the level of the total anticipated demand.

Thus it would be unreasonable to conclude that nuclear energy would be resorted to only in order to compensate for a penury of fossil fuels.

This observation is based on the following particular points : there are good possibilities for increasing coal imports, especially American coal; the oil strikes in North Africa and in other parts of the world are considerable in extent; finally, natural gas (possibly by imports or transfers of consumption) affords good prospects.

In order to assess the intrinsic scope of the supply problem, it would perhaps be useful to take an extreme hypothesis by giving an order of magnitude arrived at on the basis of a rough estimate.

If the total energy requirements for 1980, i.e., 774 x 10^6 TCE, were considered without taking account of potential American coal imports or the prospects offered by natural gas, i.e., by adopting the following hypotheses :

- that the coal consumption would remain at the 1958 level,
- that the predictions adopted for electricity produced from privileged sources would be realized,
- that the use of nuclear energy would be restricted to the scheduled 2,000 MW,
- that the entire balance of the consumption to be met in 1980 would be covered by oil products alone,

we would arrive at the conclusion that this consumption of oil products, in 1980, would be in the order of 360 x 10^6 TCE compared with 82.4 x 10^6 TCE in 1958. The ratio between oil production in 1980 and in 1958 would thus be 4.4. Such a rise in consumption is without any doubt considerable, but the imports which it would require seem, a priori, by no means impossibly large. Also, if we bear in mind the hypotheses on which this argument rests, we see that we are dealing here with an absolute maximum hypothesis.

Returning to the previous considerations, and to express the same idea in another way, it can be estimated that, however important the questions bound up with the volume of fossil fuel imports which must be predicted for the future, they would not justify the obligatory exploitation of nuclear power if its production were still not economically defensible. This conclusion shows how important it is to consider the problem of the respective production costs of the conventional and the nuclear kWh.

III. The Competitive Prospects for Nuclear Energy

18. The ability of nuclear electricity to compete in the period 1960-1980 depends essentially upon :

- the development of the cost of electricity from conventional sources and, therefore, to a decisive degree, upon the trend of costs of fossil fuels;

- the estimates of the cost of electricity produced in nuclear power plants;
- various factors which cannot be quantitatively expressed in cost schedules. Certain factors militate against nuclear energy, such as the high investment cost per net installed kW, the risk of very rapid technological obsolescence and the exaggerated fears of nuclear hazards. Others operate favourably, such as the relative abundance of nuclear materials with the enhanced security of the energy supply situation which this implies, and the need to plan ahead in any new branch of technology to avoid being overtaken by events.

These latter points are not dealt with in the study at the present stage. Nor have various other factors of importance in the structure of the energy economy been taken into consideration such as the base and peak load breakdown in Europe and the integration of very large-scale production units into the grid.

Thermal plants - Development of production costs

19. The fuels which must be taken into account for an appreciation of future competitive conditions are the following :

- coal produced by the Community,
- imported coal, mainly from the United States,
- oil, and in particular, fuel oil.

The hypotheses adopted previously for purposes of simplification render it unnecessary to examine lignite, gas and hydroelectric power.

20. The average price of coal produced in the Community will in all probability fall in line with the price, c.i.f., of American coal delivered to European ports. This will put it on a competitive footing with imported coal.

21. The price c.i.f. of American coal stands at the present time at around $ 15 the metric ton. Various factors, such as the likelihood of a boost in productivity in American mines and also of a price reduction brought about by rationalizing the handling techniques and transportation for a more extensive and regular traffic, all argue, for the twenty-year period under consideration, in favour of price stability at this $ 15 rate, or rather for a

slight drop of around $ 1.50 per metric ton. It is, however, scarcely possible to say whether even these reduced prices could remain steady in the face of a general reduction of fuel prices.

22. Recent trends in the world oil industry rule out any forecast by extrapolation of tendency. They do, however, afford some indication of the probable growth of oil consumption. Moreover, important changes have taken place during the past few years in the proving of deposits and the estimation of the volume of oil production. The most noteworthy of these are :

- confirmation of the importance of the Sahara oilfields;
- rapid development of the deposits discovered in Libya;
- opening-up of new fields in Iran;
- change in the position of Argentina, hitherto an importer but soon to be an exporter of oil;
- rise of Nigeria to the rank of producing country;
- considerable intensification of production in the USSR, which in the near future may be in a position to export substantial quantities to the free world;
- introduction of deeper-drilling techniques (depths of nearly 30,000 feet), thus opening the way for expanded production in certain oilfields now in operation;
- use of pipelines, which in certain cases and in certain conditions enables reductions to be made in delivered-consumer prices.

More detailed information on this subject will be found in Annex VI to the present memorandum.

As a result, world crude oil reserves have increased to what is probably a very considerable extent compared with their level three or four years ago. Market offerings will inevitably undergo a material expansion in the near future. In the case of certain deposits, i.e., those in the Sahara and particularly in Libya, a very distinct reduction is being achieved in the distances between sources of production on the one hand and centres of refining and consumption on the other. Furthermore, the price of oil delivered to refineries includes royalties and pipeline dues, which offer certain possibilities of price reductions. The price of refined products is itself inflated by the number of refining plants which are working below capacity.

All these convergent elements confirm the hypothesis that a temporary stabilisation will be followed by a reduction in the actual price of fuel oil in the near future. It seems reasonable to estimate that, on the average, the current theoretical price c.i.f. Rotterdam of $ 21.5 per metric ton may fall by approximately 20 %, namely to a level of around $ 17.5.

23. Account has accordingly been taken in this initial rough survey of a competitive price per kWh from conventional sources which up to 1980 is based on prices c.i.f. European ports decreasing progressively around 1965 to :

- app. $ 13.5 per ton for imported coal;
- app. $ 17.5 per ton for fuel oil.

To put the situation in a very simplified form (see Annex VII), it may be said that at present and until 1965 or so, 150-MWe conventional power plants embodying the most up-to-date improvements, consuming 2,350 Kcal per kWh and operating to 80 % of capacity, will have an average production cost of :

8.74 mills per kWh.

It may be estimated that in a few years' time, by reason of the increase in unit capacities to around 300 MWe, fixed charges will have decreased by approximately 10 %. Allowing in addition for a reduction in fuel oil prices of up to 20 % after 1965, it is reasonable to expect that in such plants it will be possible, with an 80 % load factor, to achieve a cost of :

7.34 mills per kWh.

The 80 % load factor has been employed in these calculations in order to enable a strict comparison to be made with the calculations below for nuclear power plants. The choice of this figure at this stage in the work is justified by the following considerations :

- it is technically possible and economically desirable to assign to the nuclear power plants a high load factor;
- in the early stages at all events, there will only be a small number of power stations; there will be no difficulty in finding a place at the base of the load diagram for these;

- the competitivity comparisons are drawn at the moment when the choice is made, and in their first few years of operation it is usual for plants incorporating the latest improvements to have high load factors.

It is none the less true that the base of the load diagram cannot be extended ad infinitum. After a certain time, all the most recent installations which are brought in operation may follow the same pattern of use as electricity installations in general and the load factors may thus be appreciably reduced.

This is a contingent situation and has not been specifically taken into account. To the extent that such may be useful, Annex VII to the present memorandum contains an estimate of the costs on the assumption that the load factors will develop as follows for the new capacities to be installed :

up to 1965 - 80 %
from 1965 to 1970 - 70 %
from 1970 onwards - 60 %.

These figures must be compared with the present average load for the Euratom countries, which is of the order of 43 %.

Assuming an 80 % utilisation of the new power plants to be put into operation between now and 1980 - a hypothesis which may in any case be adopted for determining the competitive positions at the time of selecting the units to be built - the costs per kWh of traditional energy would therefore be :

between now and 1965 - app. 8.74 mills per kWh;
from 1965 to 1980 - app. 7.34 mills per kWh.

Nuclear Power Plants : Outlook for Development of Production Costs per kWh.

24. What are the prospects at the present time for the competitive position of nuclear energy between now and 1980 ? As a basis for the assessment of such prospects, we have the figures derived from :

- the offers for the construction of power plants of around 150 MWe under the Euratom-US Agreement;
- the surveys made by the USAEC, which were published in August 1959;

- the PITTMAN Report on the development of the power-reactor economy.

A critical and detailed analysis of these particular factors will be carried out shortly. In the meantime, by way of initial approximation, discreet use has been made of the figures available.

It has been estimated that nuclear energy could be incorporated into the production of electrical energy on the following conditions :

- from now until 1965, production costs for 150-MWe nuclear power plants operated at an 80 % load factor will be around :
  11 mills par kWh
- between 1965 and 1970, the changes in techniques and unit sizes will bring about reductions, the most recent estimate of which is given in the PITTMAN Report, in the case of 300-MWe plants operated at an 80 % load factor. Of the various types of reactors considered in this Report, only the BWR has been adopted for the purposes of the present forecasts. Even though this type of reactor does not yield the lowest production costs, it is, together with the PWR (less favourable, according to the author, as regards the anticipated results), the only one which is based on an industrially proven technology; the forecasts of prices per kWh for all the other types are simply and solely the result of the extrapolation of research data and bear no relation to the realities of construction and operation.
  From the premises developed above, we arrive at a cost estimate of :
  7.48 mills per kWh
- from 1970 onwards, the cost will certainly decrease still further, and in the case of either the BWR type or other types of the most up-to-date design it will at all events drop below 7.48 mills per kWh.

That the cost will be reduced is to all intents and purposes certain when it is considered that a prodigious effort is being made in research into and development of technologies as yet in their infancy. It is therefore reasonable to suppose that after 1970 the improvement of plant and the reduction in fuel costs will bring down the cost per nuclear kWh to or below the level of that per conventional kWh.

As a simple illustration, moreover, it may be pointed out that according to the estimates in the PITTMAN Report the 300-MWe OMR reactors operated at an 80 % load factor will, as from 1965, have a cost lower than 7.10 mills per kWh. It must also be borne in mind that the figures in the PITTMAN Report have been arrived at on the basis of US prices for the construction of power plants and that considerable savings would be possible if the plants were built, at least in part, in Europe. Finally, it will be seen that these figures are calculated on the basis of a cost structure which is slightly different from that adopted in the present survey for determining the cost of the conventional kWh, fixed costs being estimated at 14 % of investments as against only 12 % per conventional kWh.

Thus the following trend may be anticipated :

- from now until 1965 - app. 11 mills per kWh;
- from 1965 to 1970 - app. 7.48 mills per kWh;
- from 1970 to 1980 - less than 7.34 mills per kWh.

25. Government Assistance in Lowering the Cost of the Nuclear kWh

This aspect has been mentioned here for the sake of completeness and is commented upon in Annex IX. It can scarcely, however, be said to have a permanent effect. At the very most, it is capable of exercising a transitory accelerative influence on the adoption of nuclear energy by offsetting some of the temporary disadvantages experienced by the operators of nuclear power reactors.

IV. Estimates of Future Nuclear Capacity for Electricity Production

26. The following is a comparative table of the competitive potentials in question :

Competitive Status of Conventional as Against Nuclear Energy

	Cost per kWh		Difference % between kWh nuclear and kWh conventional
	Conventional Plants	Nuclear Plants	
between now and 1965	app. 8.74 mills	app. 11 mills	+ 25
from 1965 to 1970	app. 7.34 mills	app. 7.48 mills	+ 2.5
from 1970 to 1980	app. 7.34 mills	less than 7.34 mills	- ?

It is difficult to assign to these figures a coefficient of error one way or the other.

27. Account must, however, be taken of possible differences in local situations in the load to be supplied, as well as of the influence exerted by the extra nuclear investment costs and of the partial inertia of producers when it comes to adopting new techniques. Furthermore, the margin of improvement in nuclear technology is only estimated up to 1965, whereas the improvements will extend far beyond that date.

It has therefore been broadly assumed, in the absence of other factors, that the additional electricity requirements shown in para. 14 of this memorandum can be met by the commissioning of nuclear power plants in accordance with the following gradation :

- up to 1965, for the capacity already anticipated;
- from 1965 to 1970, for half the needs mentioned above;
- from 1970 to 1980, for two-thirds of estimated new needs.

In this connection, it will be seen that the costs shown above are averages and that when the cost per nuclear kWh reaches a level approaching that per conventional kWh, the installation of nuclear power plants will already be an economic proposition in certain areas of the Community or in certain circumstances.

The schedule adopted for the phasing in of nuclear energy also satisfies the following considerations :

- new techniques are not installed immediately, even if they offer good operating prospects;
- the competitive levels are estimated with a margin of error;
- as investments in nuclear plants are higher, power rating being equal, than those in conventional plants, it follows that, given the same initial outlay, the actual power put into commission is greater in conventional than in nuclear plants.

The progressive introduction of nuclear energy as envisaged above assumes de installation of the following production capacities :

(see table overleaf)

Future Extent of Nuclear Electricity Production capacity

	Nuclear share	Needs accessible to nuclear energy in 10^9 kWh	Needs actually met by nuclear energy in 10^9 kWh	Estimated loads in hours per year	Net nuclear capacity to be installed in MW (1)
Between now and 1965	-	14	14	7.000	2.000
1965 to 1970	1/2	105	53	7.000	7.600
1970 to 1980	2/3	342	228	7.000	32.600
		461	295		42.200

28. The estimates relating to the cost per nuclear kWh are only based to a very minor extent on the results of experience. They are thus of a theoretical nature, and it is difficult to determine the margin of error, one way or the other, in the trend described above.

The adoption of nuclear energy depends on its competitivity. Any change in the competitive conditions assumed above will have its repercussions on the rate at which nuclear power plants will be constructed. It may be pointed out, by way of illustration, that if the adverse hypothesis is selected whereby nuclear power plants will not begin to compete with conventional power plants until 1970 - a hypothesis which, however, scarcely accords with the outlook at the present time - the development of nuclear plants will, at a rough calculation, result in a total capacity of around 30,000 MWe by 1980. This illustration is given solely in order to show the extent of the difference which might result from a change in the factors on which the estimates are based.

...

(1) In nuclear plants as in conventional plants, ageing will have the effect of progressively reducing the utilisation factor. In consequence, it might be necessary, in order to reach the production target, to raise the estimated nuclear power from 42,200 MWe to around 45,000 MWe.

29. Subject to a later study of all the various hypotheses which have been employed here, in the light of :

- the trend of production and prices of fossil fuels in the coming years;
- a critical survey of the performances of the industrial reactors now functioning or shortly to be put into operation;
- the actual results yielded by the Research and Development Programme,

it is therefore reasonable to believe at the present time that by 1980 the Euratom countries will have an installed nuclear capacity in the region of

40,000 MWe net.

In order to give an idea of the relative importance of this figure, it may be observed that if these forecasts are fulfilled, the amount of electrical energy of nuclear origin produced in 1980 will exceed by approximately 12 % the total volume of electricity of all sources to be produced in 1960. It will also represent around 30 % of the estimated electricity output for 1980.

ANNEX I

Probable Expansion of Industrial Production

The forecasts shown in Annexes II and III are based on an expansion of the Community's industrial production at the following rate :

Period	Annual Rate of Growth %
1955 - 1960	5.5
1960 - 1970	5
1970 - 1980	4

As regards the period 1955 - 1960, we are in possession of the figures recorded up to and including 1958, the estimated figure for 1959 and the anticipated figure for 1960, namely (in %) :

1956/55	:	8	
1957/56	:	6	
1958/57	:	3	
1959/58	:	7	(estimated)
1960/59	:	7 to 9	(anticipated)

This gives an average annual rate of increase for the entire period of 6 %.

A recent survey by the High Authority shows the annual average rate of increase for the period 1956-1959 as 5 %.

While subscribing to the view that the actual rate of increase for the first five-year period will prove to be around - and possibly higher than - 6 %, we are adopting a lower rate of 5½ % in keeping with the caution which we resolved to adopt at the outset of the present survey.

The rate of 5 % which has been assigned to the period from 1960 to 1970 has been the subject of discussion with the competent authorities of the EEC Commission. It also appeared to be reasonably moderate.

The drop to 4 % which is shown as occurring in the course of the following ten-year period might be attributed to various

reasons, including a relative slackening in the growth of certain factors of production (population) and the greater difficulty in maintaining the same rate of progress as production levels become higher and higher.

annex I

ANNEX II

General Brief Assessment of Energy Requirements

I. Method

A comprehensive econometric survey of energy requirements should examine successively :

- overall needs ;
- needs by sectors of consumption.

Analysing demand for energy by sectors makes it possible, which an overall survey does not, to take into account certain structural features in the trend, adaptation or saturation of the various sectors. On the other hand, it has the drawback of disregarding the dynamic influence exerted by the "up and coming" sectors and by new habits and customs. Thus it results, generally speaking, in estimates of future needs lower than those yielded by an overall survey method.

However, by reason of the difficulties in the matter of obtaining statistical and technical documentary material on most sectors, it is hardly possible to achieve complete results within a short time and it is therefore necessary for the moment to confine our survey to overall needs.

There is a close correlation between consumption of energy and general economic activity. An explanatory function of the development of energy should enable the influence of economic activity to be measured. In addition, it should make it possible to detect where general economic activity remains constant any reduction or increase in energy needs resulting from the action of technological factors which are assumed to follow a relatively steady trend.

From this the following function may be formulated :

$$E = Eo \ (I/Io)^{\alpha} \ e^{\gamma(t-to)}$$

in which

I represents the index of economic activity,

α the elasticity of the relationship energy consumption/ economic activity,

γ the influence of time where economic activity remains constant (may be positive or negative), and

o the base year.

More simply, this is equivalent to saying that the increase in energy is the result of two interconnected factors, namely :

(a) the influence exerted by the level of economic activity, every variation of 1 % in the index of overall economic activity involving a variation of α % in energy consumption ;

(b) regular expansion at an average rate of γ % annually, due to technological factors which tend to increase or reduce its field of application.

II. Results of statistical analysis

(a) Series employed

The series employed for consumption of primary energy corresponds to supplies of primary energy (production + imports-exports) plus the balance of external trade in secondary energy.

Industrial production has been considered as representing economic activity.

(b) Period covered

The statistical adjustment relates to the data for the periods from 1929 to 1938 and from 1948 to 1957. A thorough statistical analysis leads to the conclusion that the two periods together may be considered as a single sample.

(c) Value of parameters

The values obtained for the Community as a whole are as follows :

- an elasticity of 0.68509 between consumption of primary energy and industrial production ;
- a regression factor of 0.797 per year in the temporal development of primary energy consumption ;
- a multiple correlation coefficient of 0.975.

If R represents the rate of increase in energy and r that of industrial production, we thus have :

$$R = 0.68509\ r - 0.797$$

r and R being expressed in %.

---

(1) If $E = Eo\ e^{Rt}$

$I = Io\ e^{rt}$

the equation $E/Eo = (I/Io)^{\alpha} e^{\gamma t}$

is written $e^{Rt} = (e^{rt})^{\alpha} e^{\gamma t}$

Or, by taking the natural logarithms and dividing by t :

$$R = \alpha r + \gamma$$

III. Estimates

The estimates below are based on the expansion of industrial production at the rate shown in Annex I, i.e. :

Period	Rate of increase expressed in %
1955-1960	5.5
1960-1970	5
1970-1980	4

However, the results shown in section II above could not be extrapolated directly, as the index numbers used to estimate the parameters are calculated on the basis of 1938=100, whereas those employed for extrapolation are calculated on the basis of 1954=100.

In the case of the Community, for instance, the index 1938=100 progresses more rapidly than the index 1954=100, viz. :

$$I_{1938} = k \left(I_{1954} \right)^{1.07442}$$

We then have :

$$R = 0.73507\, r - 0.797 \quad (1)$$

(r and R being expressed in %)

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(1) We have : $E/Eo = (I/Io)^{\alpha}_{1938}\, e^{\gamma t}$

$$E/Eo = \left[(I/Io)^{1.07472}_{1954} \right]^{\alpha} e^{\gamma t}$$

$$e^{Rt} = \left[(e^{rt})^{1.07442} \right]^{\alpha} e^{\gamma t}$$

$$R = 1.07442\, \alpha r + \gamma$$

Under these conditions, primary energy needs would show the following trend :

	in 10^6 T C E	Index numbers
1955	398	100
1960	468	118
1965	540	136
1970	624	157
1975	695	175
1980	774	195

These figures include all primary energy needs, whether consumed in the original form or converted into secondary energy and, for the purposes of the present study, more particularly into electricity.

ANNEX III

Estimated Electricity Requirements

I. Method

The general observations on overall estimates and estimates by sectors which are developed in Annex II apply equally to estimates relating to electricity.

Overall electricity needs may be estimated in two ways, namely:

- firstly, the development of electrical energy may be said to be autonomous and to take place independently of any other evolutionary factor. What is required, therefore, is to extrapolate in respect of the future development the trend recorded in the past, which assumes simply and solely the continuity of the rate of development observed;
- secondly, the evolution of electrical energy needs may be linked to the development of economic activity. For the purposes of this method, a more complex one, it must be possible to determine from the analysis of the past evolution the relationships between the variables and also to estimate the parameters in a manner which is satisfactory from a statistical standpoint. Estimation by this method presupposes that the parameters will remain constant and that the relationships obtained have, economically and statistically, a reasonable chance of being maintained. Furthermore, it is necessary to adopt certain hypotheses as regards economic development in general.

(a) Extrapolation of Trends

From the graphs of the temporal series relating to electricity development it is seen that these follow an exponential trend in relation to time or that their logarithms are to an appreciable extent on straight lines.

We therefore have a relationship between electrical energy E and time t in the following form:

$$E = A\, e^{Rt}$$

or

$$\text{Log}_e E = \log_e A + Rt$$

Determination of the parameter R and the constant A may be obtained by means of an adjustment by the least squares method.

We have not yet calculated the trends. It is, however, possible to obtain a fair approximation of the value of R by taking the value resulting from a direct calculation of the rates of increase (1). We thus have:

Values of Parameter R (expressed in %)

	Period 1920 - 1939	Period 1950 - 1958	Period 1955 - 1958
Belgium	8	5.1	4.5
France	7	7.7	7.1
Germany	7.1	9.4	7
Italy	7.2	7.3	5.6
Netherlands	8.9	7.8	7
Community	7.2	8.4 (2)	6.7

It appears to us to be worth stressing the tendency towards uniformity shown by the various rates of increase. Taking account of the differences due, among other things, to the choice of the years marking the beginning and the end of the periods in question, it seems that on the whole the development of electrical energy has been averaging an annual rate of around 7% (law of doubling in ten years).

This "law" of doubling every ten years has been observed for several decades in many countries (notably the U.S. and the U.K.). Any hypothesis showing electricity output as deviating, in either an upward or a downward direction, from this trend must therefore be examined very seriously. It would, in fact, appear that the field of electricity is still open to a great many applications and that the saturation point has not been reached.

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(1) By taking as the value of E the quantity of electrical energy at the end of the period and as that of A the same quantity at the beginning of the period(i.e. Eo) and t as the period in question, we obtain: $\text{Log}_e E - \text{Log}\, Eo = R\,(t - to)$

i.e. $R = \dfrac{\text{Log}_e\, E/Eo}{n}$ where $n = t - to$

(2) The year 1950 was a year of rapid development. If we take 1951-1958, we then obtain 7.2.

(b) Development linked to Economic Activity

The function adopted is in the same form as that employed for primary energy needs as shown in Annex II.

Thus: $E/Eo = (I/Io^{\alpha} e^{\gamma (t-to)}$

In the same way, industrial production has been taken as representing economic activity.

The statistical adjustment relates to the data for the periods from 1929 to 1938 and from 1948 to 1957. A thorough statistical analysis leads to the conclusion that the two periods together may be considered as a single sample.

The results obtained are as follows:

	α	γ	Multiple Correlation Coefficiant
Belgium	0.70	2.2	0.996
France	0.66	3.7	0.999
Germany	0.79	2.7	0.993
Italy	0.46	3.4	0.998
Netherlands	0.65	3.8	0.999
Community	0.62747	3.4	0.999

Noteworthy features of the above table are:

1. the very high value of the correlation coefficients;
2. the relatively small degree of dispersion of the parameters. It would appear, however, that the value of the coefficient α is directly proportional to the degree of industrialisation of the country, this being, moreover, compensated by a lower value for the coefficient γ;
3. these values give a rate of increase in electricity which averages about 7% in the case of industrial production values of 5% to 6%.

Having thus determined the value of the parameters α and γ, it is an easy matter to establish the correspondence between the average increase in electricity and the average increase in industrial production.

If r represents the rate of increase shown by industrial production and R that shown by electricity, we have as an average :

$$R = r\alpha + \gamma \quad (1)$$

Thus for the Community as a whole we have :

$$R = 0.62747\ r + 3.4000$$

(R and r expressed in %)

Having regard to what has been said in annex II, section III on the concordance of the indices of industrial production, it may be estimated that a given rate r for industrial production will in the future have the following corresponding rate R for electricity production for the whole Community :

$$R = 0.67417\ r + 3.4000$$

i. e., for different values of R,

r	R
3	5.42251
4	5.09668
5	6.77085
6	7.44502
7	8.11919
8	8.79336

Note :

It would not appear to be out of place to compare the results obtained from the two methods in question. Thus :

- the analysis of the trends gives rates of development of around 7 % ;
- from the study of the multiple correlation between electricity, industrial production and time, parameters are obtained whose value is such that in respect of the rates of increase of industrial production actually observed we find rates of increase in electricity averaging 7 % annually.

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(1) If $E = Eo\ e^{Rt}$
$I = Io\ e^{rt}$

the equation $E/Eo = (I/Io)^{\alpha} e^{\gamma t}$
is written $e^{Rt} = (e^{rt})^{\alpha} e^{\gamma t}$

Or by taking the natural logarithms and dividing by t :

$$R = \alpha r + \gamma$$

This prompts us to make the following observation:

The hypothesis relating to the increase in industrial production is very important as regards estimating electricity requirements. It is therefore necessary to define and examine it with great care, particularly if it gives figures of needs which show appreciable variations, in either an upward or a downward direction, from the trend usually observed.

II. Estimates of Electricity Needs

According to the method which has been adopted, the annual rate of increase in electricity may be considered as:

- equal to a variable rate of increase proportional to the rate of expansion r of industrial production;
- accentuated by a constant rate reflecting the steady tendency towards extension of the field of application of electricity; i.e., $R = 0.67417\ r + 3.4000$

  R and r being expressed in %.

Assuming the same rates of increase in industrial production as those employed previously to determine primary energy needs, we obtain the following trend for electricity requirements:

(see table on following page)

Year	in 10^9 kWh	in index numbers	rate of increase % for previous period	in 10^6 T C E.
1955	185	100		97
1960	264	143	7.2	124
1965	370	200	6.8	155
1970	518	280	6.8	202
1975	701	379	6.1	259
1980	950	514	6.1	332

In this table and in the whole of the present survey, conversion of the kWh into T C E has been effected on the basis of the following equivalent values for 1 kWh:

1955	525 gr C E	or	3675 k cal
1960	470 gr C E	or	3290 k cal
1965	420 gr C E	or	2940 k cal
1970	390 gr C E	or	2730 k cal
1975	370 gr C E	or	2590 k cal
1980	350 gr C E	or	2450 k cal

These equivalent values have been determined by taking the average consumption for all power plants and not the consumption of the most modern power plants.

ANNEX IV

Comments on Estimates of Electricity Needs

(a) The Committee on Electricity (Secretariat and National Delegations of OEEC) has arrived at results quite close to but slightly lower than those shown in Annex III, the figures given for the whole of the Euratom countries being 364 x 10^9 kWh for 1965 and 673 x 10^9 kWh for 1975.

The Robinson Report also gives estimates, but only for the whole of the OEEC countries. These do not differ a great deal from those furnished by the Committee on Electricity, viz. (in 10^9 kWh):

	1965	1975
Committee on Electricity	710	1.300 ± 10%
Robinson Commission	700	1.200

(b) If the development of electricity is compared with that of all primary energy as shown in the preceding Annexes, it is seen that the total electricity, i.e., including both primary electricity (hydro and geothermic), as calculated according to the average input of the thermal power plants and so-called "secondary" (thermal) electricity converted into primary energy by the same method, accounts for an increasing percentage in relation to the total supplies of primary energy.

	Electricity converted into T C E	Total energy in 10^6 T C E	Electricity as % of energy
1955	97	398	24.4
1960	124	468	26.5
1965	155	540	28.7
1970	202	624	32.4
1975	259	695	37.3
1980	332	774	42.9

In 1956, this percentage was around 20% in the United States. This may be partly explained by the very high proportions of natural gas and oil in the supply of energy, each of these sources having a larger share than coal.

(c) It is also as well to point out that in 1959 the US electricity consumption was:

798×10^9 kWh

in respect of a population of 170×10^6 inhabitants, or a specific consumption per inhabitant of:

4.5×10^3 kWh.

For the same year, the Euratom Community had a consumption of:

240×10^9 kWh

in respect of a population of 160×10^6 inhabitants, or a specific consumption of:

1.4×10^3 kWh.

Consumption per inhabitant in the Euratom countries was thus 30% of that in the US.

In 1980, on the basis of a consumption of 950×10^9 kWh and a population of 190×10^6 inhabitants, specific consumption for the Euratom Community will amount to:

5.0×10^3 kWh per inhabitant, which only represents 125% of US consumption per inhabitant for 1956.

Moreover, the target consumption for the USSR in 1972 under the Second Seven-Year Plan is a maximum of:

900×10^9 kWh

in respect of an estimated population of 250×10^6 inhabitants, i.e., a target per inhabitant in 1972 (1) of:

3.6×10^3 kWh.

In the light of the foregoing, the estimated electricity consumption for EURATOM in 1980 may be said to be modest.

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(1) According to other information, the USSR's target for 1980 is

$2{,}300 \times 10^9$ kWh

in respect of an estimated population of around 270×10^6 inhabitants, i.e., a target per inhabitant in 1980 of:

8.5×10^3 kWh

Drillings are being made to depths of 25,000 - 30,000 feet, the wells in question having previously been less than 10,000 feet deep.

7. Nigeria has become an exporter, not, it is true, of very large quantities at the moment. But such exports are being shipped from a port far nearer to Europe than Venezuela's.

8. Argentina is already an exporter.

9. The United States production industry, notably in Texas, is working below capacity: four days a week.

The world's refineries are frequently under-supplied.

ANNEX V

Electricity derived from privileged sources

This is electricity which is the inevitable product of certain sources of energy the development of which would be virtually abandoned if they did not yield electricity.

(a) Lignite, blast-furnace gas, refuse coal

The initial report on a coordinated energy policy (Mixed Committee - April 1959) gave an estimate of electricity production derived from these various sources (in 10^9 kWh) for the years 1960, 1965 and 1975. The series has been completed by interpolating the figure for 1970 and extrapolating that for 1980 according to the same tendency. The figures for these years are shown in parentheses.

	Power plants using lignite	Power plants using blast-furnace gas in 10^9 kWh	Power plants using refuse coal
1955	19.2	7.9	23.2
1960	32.5	11.6	42.0
1965	49.9	14.0	58.0
1970	(56.0)	(16.5)	(74.0)
1975	62.1	19.0	91.0
1980	(68.0)	(22.0)	(105.0)

This table prompts the following observations :

1. The production of the power plants using lignite appears to be very high. In this connection, the Robinson Report anticipates a doubling of production of lignite for the OEEC countries (with Germany accounting for 90 % thereof) between 1955 and 1975. Even assuming a decrease in production of briquettes and a reduction in specific consumption one hesitates to forecast a trebling of the production of the plants using lignite over these twenty years. Barring obstacles at the outset, however, one might consider it possible that, in the face of the threat from low-price nuclear energy, the development of the deposits could be stepped up to some extent.

2. The production of plants using refuse coal also seems too high. If, in fact, coal output is stabilised at around its 1955 level, refuse coal, whatever correctives may be applied (changes in methods of extraction, changes in quality, improvements in output, use of products previously abandoned, etc.), represent a markedly increasing proportion of the overall production. There is, however, an interaction between consumption of refuse coal and that of marketable products lower down in the scale.

(b) Hydro and geothermic energy

As to the probable trend of hydroelectric and geothermic energy, we have the estimates of the Mixed Committee and those of the OEEC Committee on Electricity.

	Mixed Committee's estimates in 10^9 kWh	O E E C 's estimates in 10^9 kWh
1955	70.2	68.2
1960	85.7	-
1965	105	99.8
1970	(120)	-
1975	135	128.3
1980	(150)	-

The estimates furnished by the OEEC Committee on Electricity are thus slightly lower than those shown by the Mixed Committee. The estimates produced by the Robinson Committee for the whole of the OEEC countries are themselves a little below those of the Electricity Committee.

(c) Power plants using natural gas

Natural gas is tending to develop in a fairly autonomous manner. The Mixed Committee's estimates of production of electricity by plants using natural gas are as follows (in 10^9 kWh) :

1955 :	1.4
1960 :	4.1
1965 :	9.7
1970 :	(13.5)
1975 :	17.9
1980 :	(25)

This rate of development differs little from that of the expansion of natural gas production as shown in the Robinson Report. The possibilities offered by natural gas in the Sahara have not been taken into consideration here. Fulfilment of these possibilities might offset any over-optimism with which the prospects for the increase in lignite and inferior coal products might have been assessed.

x x

x

In conclusion, then, it may be said that for the whole of the sources dealt with above the Mixed Committee's estimates appear to be very high, but that amounts, once again, to adopting a minimum hypothesis as these estimates have to be deducted from the total needs in order to determine the part available for production of nuclear energy. We accordingly propose to do this from considerations of homogeneity and caution.

Under these conditions, production of electricity derived from privileged sources shows the following pattern :

Production derived from privileged sources

Year	in 10^9 kWh	in 10^6 T C E
1955	121.9	64
1960	175.9	83
1965	236.6	100
1970	280.0	109
1975	325.0	120
1980	370.0	129

ANNEX VI

Evolution of World Oil Economy

1. It is advisable to take into account all new sources of production, since:

- either they will raise former consuming countries to the ranks of exporting countries,
- or they will, in certain countries, replace imports,

in such a way that the supplementary exporting capacities will add to the shifts in supplies and thus broaden the world market.

2. We refer to the extensive information which has been published on production in the Sahara of both oil and natural gas; the latter may also bring about shifts in consumption and supplies.

3. We also refer to the material which has been published on Libya.

Newly discovered wells, like Zelten, have a flow of 14,200 T/d, and this at a distance of around 180 km from the North African coast opposite Sicily.

General appraisals have been expressed according to which a new Middle East may be arising here, but account must also be taken of the possible influence of political factors in a country liable to instability.

4. Over the past eight years, demand for energy in the United Kingdom is said to have increased by 24×10^6 TCE. This extra demand has been met to an appreciable extent by an increase in oil consumption of the order of 20×10^6 TCE.

5. As regards the USSR, the following information deserves attention:

(a) within a few years oil exports will have increased by 30×10^6 tons;

(b) in 1959, exports of oil to the free world already stood at 13×10^6 tons;

(c) raising of oil production, according to the Plan, from

113×10^6 tons in 1958, to
230×10^6 tons in 1965.

Increase in oil production at the rate of 11% annually. In the case of natural gas, the corresponding increase is 26%.

It is the Russian opinion, in relation to the development of other sources of energy, that oil and gas are new means towards higher productivity;

(d) recent discoveries of oil in:

- Uzbekistan
- Turkmenia (new Middle East, according to Minister Antropov)
- Siberia, Irkutsk and Berezovo
- and promising geological similarity along the Lower Volga;

(e) for transport purposes, creation of two new oil ports:

- Klaipéda (Lithuania)
- Ventspils (Latvia), to serve the Baltic;

(f) new 4,000 km pipeline from the Urals, with branches to Poland, Eastern Germany, Hungary, Czechoslovakia, with a flow of 15×10^6 tons annually, and four refineries of 1 to 4×10^6 tons annual capacity, to be completed in four years, i.e. before the end of 1963.

6. Substantial redrillings are being carried out at considerable depths. Should these prove successful, the former surface installations may be used.

Examples of successful projects in Venezuela; by deepening, Concepción and La Paz have recorded an increase from 5,000 b/d to 250,000 b/d.

Deepening works are in progress in:

- Iran
- Qatar
- Burma.

ANNEX VII

Estimates of costs per kWh

A. Electricity from conventional thermal sources

It is extremely difficult to select a type of conventional power plant which for the six Euratom countries may be said to represent the average modern conventional power plant. We have therefore finally taken a type of plant whose features and operating results have been used for reference when examining the probable operating results of the first nuclear power plants to be built under the US agreement.

This is a power plant :

- of 150 MW net
- having a cost of 135 dollars per installed kW, which, with interest on capital during construction at 6 % for two years, comes to 151 dollars per installed kWh
- whose fixed costs are around 12 % of the investments
- whose operating and maintenance costs are 4.5 % of the investments.

Fuel (6,800 Kcal/kg) costs 15 dollars per tonne (or 2.2 dollars per 10^6 Kcal). Consumption per kWh is 2,350 Kcal.

The load factor is 80 %.

According to these hypotheses, the price per kWh is 8.74 mills (see details in table below).

We repeat that this figure may vary appreciably from country to country, but that, after consultation with certain electricity firms, it appears to us to be reasonably representative.

As said in the text of this memorandum, we have, in order to keep within the minimum hypothesis, assumed that the raising of the capacities from 150 MW to 300 MW and the few technical improvements likely to be made in the normal course might reduce investments by 10 % after 1965, and also that the fuel load could be reduced by around 20 % after 1965, which gives the following table for the breakdown of expenditure :

Cost per kWh in mills

	Before 1965	After 1965
F	2.58	2.32
V	5.19	4.15
O	0.97	0.87
	8.74	7.34

B. Electricity from nuclear sources

The table below shows two estimates from the Pittman Report. They are calculated for 300 MW power plants, utilised at 80 % capacity, and apply to the period from 1965 onwards.

Cost per kWh in mills

	B W R	O M R approximation
F	4.31	3.65
V	2.29	2.11
O	0.88	1.34
	7.48	7.10

Adjustment of these US estimates to European conditions would very probably give lower figures. A comparison of building costs favours Europe ; moreover, counting the fixed costs for 12 % of the investments, as we have done in the case of the conventional power plants (see "A" above), instead of 14 % as taken by Mr. Pittman, we obtain the following figures for the total cost :

B W R : 6.87 mills per kWh
O M R : 6.57 mills per kWh

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ANNEX VIII

Evolution of Cost per kWh as a Function of the Utilisation Factor

A. - Conventional Thermal Plants

1. - Prior to 1965

	80 %	70 %	60 %
F	2.58	2.95	3.44
V	5.19	5.19	5.19
O	0.97	(0.485)	(0.485)
		(0.544)	(0.648)
	8.74	9.18	9.76

2. - After 1965

	80 %	70 %	60 %
F	2.32	2.65	3.09
V	4.15	4.15	4.15
O	0.87	(0.435)	(0.435)
		(0.497)	(0.580)
	7.34	7.73	8.255

B. - Nuclear Plants.

1. - B W R Pittman.

	80 %	70 %	60 %
F	4.31	4.92	5.747
V	2.29	2.29	2.29
O	0.88	(0.50)	(0.587)
		(0.44)	(0.44)
	7.48	8.15	9.064

2. - O M R Pittmann (Approximation)

	80 %	70 %	60 %
F	3.65	4.17	4.866
V	2.11	2.11	2.11
O	1.34	(0.389)	(0.453)
		(1.00)	(1.00)
	7.10	7.67	8.429

ANNEX IX

Government Assistance in Covering
Operating Costs of Power Plants

I. Aid given by the German Federal Government for the AKS Project (Stuttgart).

Negotiations between the Government and AKS have not yet been completed. According to information received before January 15, 1960, the Federal Government proposes to set aside a sum of DM 100 million to make good up to 50 % of the annual operating losses, which will be calculated in accordance with a formula to be decided upon. Under the financing plan, submitted in the proposal, AKS sets Government aid at DM 15 million for each of the first few years. The balance could be used as a guarantee for bank credits. But these figures and the proposals for the following years have not yet been finally fixed.

II. Italian Government's Aid to SENN Power Plant

(1) No provisions have hitherto been made in Italy as regards assistance to nuclear power plants.

(2) For the hydroelectric and thermal power plants, the following arrangements have been made :

a) Hydroelectric Power plants

contribution to building :

- 4,500 lire, or 7.26 dollars/kW per year over a period of 15 years

contribution to operation costs :

- varies according to the type of plant; may be estimated at 4.5 to 5.5 mills/kWh.

b) Thermal Plants

contribution to building : 1,500 lire or 2.42 dollars/kW per year from date of acceptance tests until December 31, 1971.

contribution to operation costs :

- 3.95 mills/kWh up to production corresponding to effective power utilisation of 2,000 hours a year,
- 0.8 mills/kWh above 2,000 hours a year.

(3) In the case of extension, to the nuclear plants of one or other of these systems as they are, SENN (150 MW - 7,000 operating hours per year) would receive :

a) either : by application of the provisions relating to hydro-electric power plants :

- 1,089,000 dollars a year for the first fifteen years (total contribution around 16.3 million dollars), as contribution to building,
- annual contribution to operation costs which may be of the order of 4.5 million dollars;

or

b) by application of the provisions relating to thermal power plants :

- 363,000 dollars a year, from October 1963 to December 31, 1971, as contribution to building (total contribution : around 3 million dollars).
- 1,785,000 dollars a year as contribution to operation costs.

4) It is not, however, impossible that for the nuclear power plants an entirely special form of assistance will be adopted, quite different from that applying to the thermal or the hydroelectric power plants.

III. Assistance from Belgian Government for the Belgian Share in the Chooz Power Plant

This has not yet been fixed. Consideration is being given to the idea of assistance designed to reduce appreciably the rate of interest on part of the loans which are to be contracted.

IV. Assistance from French Government for Same Power Plant

None is contemplated, but EDF is a public utility.

LETTER, R. McKINNEY TO DE R. VAN ZUYDEWIJN P.N.E.M.

I regret that the attempt made by Messrs. Miller and Hamilton to get together with you during their very brief stay in Holland last week was unsuccessful. It was, of course, extremely short notice.

The purpose of their attempted visit was to ask whether you are familiar with current efforts in the United States by General Electric and Westinghouse to obtain contracts with Pacific Gas & Electric Co. and Southern California Edison Co. for the construction of atomic power plants on the order of 300 MWe. Preliminary indications are that such plants in California might yield atomic power in the cost range of 7.5 to 10 mils per KWH.

What is of considerable interest to us is your own estimate of whether plants of this size or even larger could be of any interest in the Netherlands. It begins to seem likely that it is these very large plants which may first find an economically competitive place.

We appreciate that these plants may lie beyond what is reasonable to place in the Dutch overall system, but we would be interested in your reaction. Of course, any report of further activities by you and your colleagues looking to a nuclear power project either under the United States-Euratom program or outside it since our last visit with you in January would be of interest. This inquiry is, of course, in connection with our continued effort to collect facts in connection with our study.

LETTER REPLY, J. H. RIJKES, P.N.E.M. TO R. McKINNEY

In reply to your above-mentioned letter we inform you that in fact at this stage we are not interested in a nuclear powerplant of the size of 300 MW or more.

On the contrary our interest is directed on a plant with a size as small as possible, with which:

(*a*) research can be performed a.o. in connection with the optimalising of the fuel-cycle;

(*b*) experience can be obtained, from which conclusions may be drawn for the construction of a larger plant (about 150 MW);

(*c*) the Netherlands Industries can provide their share not only for the conventional part of the plant, but also for the atomic part.

On the other hand we are very thankful for your information and we are glad having made acquaintance with Mr. Miller an Mr. Hamilton. Mr. De Roy Van Zuydewijn being on holidays, I write also in his name, stating that we highly regret not having met them again.

A NEW LOOK AT EURATOM

Statement to the Joint Committee on Atomic Energy
by Robert McKinney, Washington, D. C., May 20,1959

My name is Robert McKinney. I am editor and publisher of the Santa Fe New Mexican. In 1955-1956 I served as Chairman of the Panel on the Impact of the Peaceful Uses of Atomic Energy which submitted a comprehensive report to this Committee. In 1957-1958 I served as the first United States Representative to the International Atomic Energy Agency in Vienna. Last September I served as one of the United States representatives to the International Atoms for Peace Conference in Geneva.

From the beginning, the United States has looked at the peaceful uses of atomic energy from two standpoints:

1. How we may use them here at home for our own benefit.

2. How we may use them abroad for strengthening the Free World.

What once seemed a wise course of action may, under changed circumstances, prove unsuitable. However external conditions change, we must continue to look at things from these same two fixed and unchanging points of view: benefit to the United States, at home and abroad.

At the second Geneva Atoms for Peace Conference last September I had the opportunity of expressing to several members of this Committee my increasing conviction that circumstances have changed materially, and that we need to rethink from scratch the way in which the United States employs the peaceful uses of atomic energy as instruments in international relations.

Having in mind that the European Atomic Energy Community approaches a critical date on May 28th when statements of intent to submit proposals for the construction of plants contemplated in the joint United States-Euratom agreement are due, I took advantage of a recent trip abroad to discuss the situation with

European business men, scientists and government officials. I am grateful for the invitation of your chairman to discuss my observations and conclusions with the Joint Committee. In a nutshell, I have come to two conclusions:

1. That the joint United States-Euratom program for civilian atomic power is not now likely to proceed at a pace which, in relation to our own time scale, will pay material dividends to American technology.

2. That a new concept for atomic cooperation between the United States and the European Community is therefore necessary.

As originally conceived in the Brussels Report of May, 1956, Euratom had two objectives: the first was research and exchange of information in the atomic field. Creation of a center "to complement the research pursued by national, governmental or private bodies" was proposed. The second objective was the development of investments, common installations, a supply of nuclear fuels, and other overhead services for atomic electric power plants. These are both valid objectives; they are, in fact, exactly what the United States Atomic Energy Commission cuts across state lines to do here in America.

Then came the Suez Incident. After it, as was proper, a new study was made -- a study which we in business would call a market analysis. All of us have made them and all of us have later changed them, for the hallmark of success in business is not infallibility but adaptability to change. The market analysis, entitled "Target for Euratom," called for the creation of 15 million kilowatts of atomic electric generating capacity by 1967. This target was arrived at in the clouded light of the political, economic and nuclear technological factors existing around the time of Suez. At that point it then seemed that Western Europe might permanently remain a dollar-short, fuel-short, high-cost energy area increasingly vulnerable to the interruption of fuel imports. Euratom then seemed to offer a mechanism, fortunately already in the process of creation, which would conserve foreign exchange and provide an alternative power source competitive with fossil fuels as to cost and less vulnerable to being cut off.

As a first step, an interim, short-term goal of one million kilowatts of atomic power by 1963 was planned under joint U.S.-Euratom sponsorship. The motivation for this American support was said to be strengthening the Six Nations' economic base as a defensive shield and future dividends to American atomic technology.

Inasmuch as statements of intent to submit proposals for construction of the atomic power plants contemplated in the joint U.S.-Euratom program are due May 28, it is perhaps appropriate to review these earlier beliefs and conclusions. The points which I shall attempt to develop today are these:

1. The factors which seemed controlling at the time of Suez are no longer controlling; hence the target of 15 million atomic kilowatts by 1967 should be re-examined.

2. The construction, meanwhile, of several atomic power plants in Western Europe will serve the valid purpose of providing the Six Nations and the United States with design, engineering and operating experience; it will not be catastrophic, however, if the proposals do not add up to one million kilowatts or if the plants proposed are not finished by the date now set.

3. Whatever importance one attaches to either of these programs, there is a paramount role for Euratom to play in the integration and acceleration of European science and technology, for transmission to the United States and the rest of the free world.

Let us take up the first point: whether the conditions thought controlling at the time of Suez were permanent or temporary.

The conservation of exchange argument was weakened if not made obsolete by the action of Western European countries last January on currency convertibility. What once seemed a permanent dollar shortage is now seen to be an ebbing tide.

The specific goal of kilowatts of atomic power -- however great its merit appeared in 1956 -- seems much less urgent today, nor can one see greater urgency in at least the middle future. Clearly, in the long run Western Europe will have a huge power demand. It is not clear what energy sources will provide that power --

perhaps among them sources not yet harnessed. In the meantime, it is good sense to carry on continuing research and development in the hope of realizing competitive atomic power. But practical men must draw a line under the word competitive. With a freer Western European economy, with currency convertibility, with expanding export trade, atomic fuels will have to stand on their own feet in competition with coal and oil.

The cold light of dawn often gives new perspective. In 1959 we in the United States have found that the real costs of building nuclear power plants are much higher than we assumed in the "impressionistic" period of atomic energy, around the time of the first Geneva Atoms for Peace Conference in 1955.

Many of you will remember the keynote address of the 1955 Geneva Conference. Taking its text from Palmer Putnam's "Energy for the Future," it applied the Malthusian doctrine to the world energy situation and postulated atomic power as the only solution apparent. As a result, however, of the many diverse and often conflicting solutions produced by industrial technology, almost every shortage of the post-war period has now become a surplus.

In the six nations that comprise Euratom, unsold coal stockpiles are excessive. Unemployment and labor unrest are mounting. Imports from the United States have been embargoed. Europe's oldest community effort, the European Coal and Steel Community, took a serious setback May 14th with the rejection by the foreign ministers of France, Germany and Italy of the high authority's proposed solution to the "manifest crisis." Press dispatches report the atmosphere of pessimism and confusion as extreme, and say that the Coal and Steel Community may now be by-passed by efforts to solve the crisis on nationalistic bases.

Yet, even if coal is in over-supply today, certainly coal cannot by itself meet Europe's huge energy requirements of the more distant future. What of the logical next alternate energy source -- oil? Looming behind today's headlines of

overproduction from existing oil fields is the unknown but huge potential of unexploited world-wide deposits.

Before long, natural gas will make in Western Europe the same revolution in cost and convenience that it has already made in the United States.

The conclusion seems inescapable that any shortage of fossil fuels has receded farther into the future. It seems, also, that the pressure of overproduction will keep coal and oil prices down, even in an inflationary period. As for Soviet activities, they are more likely to drive prices down than up.

What the Suez crisis proved was the exact opposite of the public conception. Suez demonstrated a basic independence of Western Europe from oil deposits in the Middle East. Suez set the limits to what political regimes in oil producing countries can do. Realistically, they can neither cut off supplies nor raise prices. They are limited to trying to keep at home a greater percentage of a diminishing profit.

My second point calls for a few words on nuclear power, about which there are also deep questions -- questions of whether present-day technology can provide atomic kilowatts at competitive costs even in areas where fossil fuel prices are high. There is genuine doubt about the type of atomic unit which will best meet the competition of carbon fuels.

Although effective thermonuclear reactors -- by passing a uranium-based energy source -- appear to be distant in time, other developments may not be. Already there has been a minor revolution in the type of fuel element for atomic reactors. There are fascinating developments in the direct conversion of heat energy to electricity. Should these be perfected -- and in five years we are apt to see further advances beyond those recently made at the Los Alamos Scientific

Laboratory -- the whole cycle of use of a hot working fluid to drive a turbine, which in turn drives an electrical generator, could be eliminated.

With all the factors I have mentioned now in mind, one is forced to the conclusion that Western Europe's present need for atomic power can scarcely be any greater than the need in the United States or the USSR. Having in mind that technical manpower and budgets are even more restricted in Western Europe than in America and the Soviet Union, it may be that Western Europe's justification for near term atomic kilowatts is even less. In any event one must admit that the risks of proceeding at once on the commercial application of today's technology are appreciable.

True, industrially advanced nations should work toward the attainment of economic nuclear power -- but they should work at a rate consistent with technological resources and developments, not with a fear of impending disaster if the goal is not achieved in the next few years. We shall soon know whether hard-headed European business men consider that the technologic return in operating experience from a Continental reactor complex generating one million kilowatts about 1963 seems worth the substantially higher expenditures which now seem inevitable.

Those who support the program believe that it is of reasonable and manageable proportions, and that it is needed to bring Western European power technology up to the level of the United States, the United Kingdom and the Soviet Union. However, I believe that such a program by 1963, in the light of Europe's present capabilities and prospective needs, is toward the upper range of feasible emphasis on atomic electric power generation.

We must face the fact that Europe's economic needs for nuclear kilowatts have receded. We must therefore face the consequent fact that atomic kilowatts are less essential to the political objectives of the Six Nations and the United States concerning the economy of Western Europe. We might even ask whether atomic kilowatts for the sake of technological prestige carry as much weight post-Sputnik as they did pre-Sputnik.

We can wind up my second point in these few words: If European utilities come in with realistic proposals for one million kilowatts, I say, "More power to them." If they do not, there is no cause for despair, for elsewhere in Euratom's nobly motivated effort towards international cooperation there is a course of action with challenge enough for all.

We now come to the third point: the role Euratom can play in the integration of European science and technology, and the transmission of its developments to the United States and the rest of the free world.

The successful application of technology to the problem of increasing living standards rests generally on the level of technical sophistication of whatever industrial complex is involved. Specifically it rests on the sophistication of the individuals who plan, build and operate the complex. This whole edifice of technology, in turn, stands on a foundation of basic scientific research of the type performed primarily in universities and carried on to some extent in industrial and government laboratories. Although performed with little thought of immediate profit, this research is the source of those skills, those discoveries and that greater understanding of the physical world without which technologic progress could go no further. To try to force economic and technologic advancement without paying parallel attention to their essential foundation on science would be to eat our seed without planting more.

I did not go abroad to dispraise European scientific attainments. What I saw there convinced me that we become more indebted to European men of science every day.

There is, however, a wide and growing disparity between Western Europe and the United States in the technologic and scientific bases on which future economic growth must be built. In atomic science, for example, the United States has about the same number of each type of particle accelerator as the rest of the world put together. Support of scientific research and development by American industry and government -- especially in the new fields of space and the atom -- has expanded enormously. Sheer physical plant is not the be-all of any scientific activity. There are,

however, an increasing number of experiments in which the limiting factor is the availability of a large staff, drawing together many special skills, and extensive, expensive special-purpose facilities.

The difference is entirely one of critical mass. Extending as it does across the whole of North America, having close relationship with a continent-sized complex of academic, industrial and government laboratories, the United States scientific community is bound to enjoy advantages not available in smaller political and economic units -- such as is the case on the presently fragmented European continent. If Western European science has been able to accomplish so much with its present system and facilities, we have every reason to expect more from a more broadly-based scientific community.

To me, this very difficulty suggests a proper course of action for the European Atomic Energy Community: Euratom's emphasis should be on the collective creation of new scientific and technical resources.

The United States is involved in Euratom research. We and the Six Nations have undertaken to provide 50 million dollars each, over five years, for research and development centered on improvement of performance of reactors involved in the one million kilowatt program. Even if proposals totaling one million kilowatts are not received, the United States should think twice before reducing the research element of its financial support -- although it would be logical to broaden and redirect it.

The Six Nation Treaty authorized Euratom to spend up to 215 million dollars over five years for a joint nuclear research center and outside contract work. The scientific and technical committee which is to advise the Euratom Commission on setting up the center has been appointed but no report has been received and no site chosen.

The concept I have in mind is to consider that the operative idea behind Euratom is not atomic kilowatts, but rather the integration of the European scientific and technical community.

If, however, we expand the concept behind Euratom, we then may ask whether the central research activities need necessarily be confined to the atomic field. At the time of Euratom's conception the atom was the newest frontier of science, but newer frontiers have since emerged. True, atomic science calls for a breadth of knowledge and skills; it has a diversity of applications in physics, chemistry and biology, as well as a wide range of specific practical uses in medicine, agriculture, industry and even space travel. Nevertheless, activities across the whole scientific spectrum could help build a stronger, broader technologic foundation for the European Community.

Such a broadening of the purpose of Euratom would be wholly consistent with the objective of the United States to bulwark the economy of Western Europe. There is even a sense of urgency for this expansion, when we reflect on the shortage of engineers and technicians to plan, build and run Western Europe's expanding industrial complex.

When we consider the duplication of effort in design, the multiplicity of types and the conflicts in specifications for equipment inescapable in the presently fragmented Europe, there is some reason to wonder whether the technical manpower shortage is not more apparent than real. By having an excessive variety of different characteristics for equipments destined to perform in fact the same tasks, the whole Atlantic community multiplies by a large factor the number of talented persons necessary to achieve a given objective. Greater uniformity would free much of this talent.

Perhaps Euratom in all its phases might in time come to be known by the name of what in fact it would then be: The European Scientific and Technical Community. Specifically, I envisage an organization having as its center a laboratory, equipped with nuclear and other facilities, open to qualified people from the 15 nations of the Atlantic Community, and having as its function the advancement of

science and technology on a broad front. Its program would go beyond that contemplated in the present Euratom concept and would include research and training in the various aspects of basic science. There would be a parallel structure devoted to practical problems of engineering and instrumentation. The provision in the Euratom Treaty that "an institution at university level shall be set up" may be the seed of an all-European seat of higher learning.

The United States has a firm commitment to Euratom and I am not suggesting that we back out of it. But I believe this new concept would given the United States reason to broaden its present commitment for trans-Atlantic research support to permit the sum now earmarked to be spent, not only on applied research and product development in the restricted sense of the present United States-Euratom agreement, but to allow European researchers to follow the ramifications of basic scientific inquiry wherever they might lead. For one example, using atomic tracers and radiation sources we can explore the uncharted field of petro-chemicals. Perhaps we may discover that coal and oil are so valuable as chemicals that it is waste to burn them as fuel. If so, there would then be a very logical gap for atomic power to fill.

Great as are the advantages of economic integration, we must not blind ourselves to the many practical difficulties which lie in the way. Long-established national hierarchies in government, business and finance will continue dominant for some time to come.

Many of these practical difficulties can be by-passed when efforts are directed where national interests are not yet vested -- for example, to the construction, management and use of extensive, expensive, special-purpose scientific

and technical facilities. An excellent case comes to mind: "Dragon," in which Euratom is joining with other Western European nations and the United Kingdom to build an advanced, "non-proven" reactor costing 38 million dollars.

There will always be important tasks in science and technology within the capabilities of single small nations. Increasingly, however, there will emerge new tasks which will require the capabilities of larger units such as the scientific and technical communities of the United States, the British Commonwealth, and potentially, Western Europe. With this enlarged objective for Euratom, there will be, first, an immediate and true integration of the Six Nations in areas where practical obstacles are less severe. Second, it will be desirable and simple for other Western European nations to join the Six.

Other tasks will require the capabilities of units even larger than the United States, the British Commonwealth and Western Europe. Today there are scientific and technical experiments which can be done -- if at all -- only on scales so big that, although they might lie within the potential of the United States, the British Commonwealth or Western Europe, attempting them would do harm to the budgets and manpower of other important projects or involve wasteful duplication. Space exploration is an example of the former, solar energy of the latter. Such tasks should become joint ventures of the whole Atlantic Community.

The role of science and technology in the integration of the Atlantic Community is beyond the scope of the discussion here today. It is to be hoped, however, that at the Atlantic Congress in London next month the subcommittee on scientific and technical cooperation, under its chairmanship of the former head of Euratom, Louis Armand of France, will be able to offer some constructive proposals.

Whatever we individually think of the value of foreign military aid, American support in strengthening the scientific and technologic foundations of our close allies would be consistent with our most basic national objectives.

Euratom has a going organization and momentum which should not be wasted. Narrowly oriented though it may now be, Euratom is a living structure of which we can make good use. The 1956 problems Euratom was to have solved -- a fuel shortage and insufficient dollar resources to meet that shortage -- have resolved themselves for the present. The more fundamental problems Euratom can now help solve will not resolve themselves. If these opportunities can be realized with American help, there will be real dividends to American science and technology at home and to American foreign policy objectives abroad.

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UNITED KINGDOM NUCLEAR ENERGY PROGRAM

(The following is the text of the White Paper presented to the British Parliament June 20, 1960, by the Ministry of Power:)

INTRODUCTION

In 1955 "A Program of Nuclear Power" was presented to Parliament (Cmd. 9389) outlining provisional proposals for the building of nuclear power stations to give a capacity of 1,500-2,000 megawatts by 1965. Because of the fuel situation and the further technical progress that had been made, the Government announced in March 1957 its intention to accelerate this program and adopt as the basis for planning a range of 5,000-6,000 megawatts of nuclear capacity by the end of 1965. Due to restrictions on capital expenditure it was announced in October 1957 that this date would be extended to the end of 1966. Details of this expansion were given in the appendix to the White Paper on "Capital Investment in the Coal, Gas and Electricity Industries" (Cmnd. 132) presented to Parliament in April 1957. Five nuclear power stations are being built and two more have been approved; the earlier stations will come into operation in 1961 and all seven should be in operation by 1966. These seven stations will have a total output capacity of approximately 3,000 megawatts. To reach a total capacity of 5,000 to 6,000 megawatts by the end of 1966 it would be necessary for the Electricity Authorities to place exceptionally large orders for nuclear capacity during the next 2 years for commissioning in 1965 and 1966.

2. Since 1957 coal has become plentiful and oil supply prospects have also improved. The need on fuel supply grounds for an immediate and sharp acceleration in the rate of ordering nuclear capacity has therefore passed.

3. The English and Scottish Electricity Authorities in consultation with the Atomic Energy Authority have therefore reexamined the program with the Government in the light of these changes and of the latest estimates of nuclear and conventional costs and the future availability of primary fuels to meet our growing energy needs.

COMPARATIVE COSTS OF NUCLEAR AND CONVENTIONAL POWER

4. Although the cost of electricity from the first nuclear stations to be commissioned next year will be rather higher than earlier estimates, the costs of later stations are following closely the downward trend foreseen in 1957. What was not then foreseen was the extent of the fall which has also taken place in the costs of conventional power from new stations. The development of large generating sets has reduced the capital cost of these new stations, the use of higher steam temperatures and pressures has increased their efficiency, and careful siting near to low-priced coal sources has reduced the delivered cost of coal to them. But nuclear costs, in which capital charges are the major element, are falling even faster. For stations designed today, conventional power costs are about 25 percent less than nuclear costs in the United Kingdom but the Government is advised that nuclear generation for base load purposes is likely to become cheaper than conventional generation by about 1970.

PRIMARY FUEL SUPPLIES

5. Despite the present world surplus of coal and oil, we still face the eventual prospect that our growing energy demands will call for more

and more supplies of nuclear power. By 1975 power stations will be consuming the equivalent of some 125 million tons of coal a year—well over double the present rate—and by the 1980's their annual requirements could well reach the equivalent of 200 million tons of coal. Although oil seems likely to remain plentiful for many years it would not be prudent to rely only upon imported oil to supplement coal to the extent implied by these estimates.

6. In the long run we shall therefore need increasing supplies of nuclear power. In about 10 years' time it should be cheaper to generate base load in nuclear stations than in conventional stations provided that we achieve the technological progress that is expected. To secure this we must continue to build nuclear stations on an adequate scale.

THE IMMEDIATE FUTURE

7. In these circumstances the Government has decided, in agreement with the Authorities concerned, that the national interest will best be served by continuing, for the time being, to place orders for nuclear stations at the rate of roughly one every year. The capacity of individual stations is likely to increase, so that the effect of this decision should be a steadily rising rate of nuclear commissioning which should give the country about 5,000 megawatts of capacity in 1968.

CAPITAL COST

8. Compared with the 1957 program, and after allowing for more conventional stations, it is estimated that this rate of ordering will reduce by some £90 million the cost of power stations to be commissioned during the next 7 years. There will, however, be some loss to the Atomic Energy Authority.

THE NUCLEAR PLANT INDUSTRY

9. The proposed rate of ordering means that at any time there should be five or six stations in various stages of development from design to commissioning. This should fully maintain the rate of development of our nuclear technology and should also sustain a nuclear plant industry capable of competing for oversea business and of expanding to meet the higher level of our own future needs. The Atomic Energy Authority's prototype of the advanced gas cooled reactor at Windscale is now nearing completion and the placing of an order for a commercial scale station of this design will be considered when sufficient information is available.

EXCERPT FROM LETTER TO LORD PLOWDEN, CHAIRMAN, UKAEA, FROM SENATOR ANDERSON, CHAIRMAN, JCAE

* * * * * * *

I am addressing requests for assistance. * * * to various national, regional and international organizations. It would be especially helpful if we could have the benefit of assistance from your Authority. Specifically we would appreciate receiving:

1. A statement of your current views on the present and prospective state of technology in the United Kingdom, with special emphasis on civilian atomic power—both fission and fusion. This would include details of present and prospective construction and

operating costs both for conventional and atomic power plants;

2. A statement of the current plans of the United Kingdom for assisting other individual nations, and regional or international organizations, in forwarding the use of atomic energy for peaceful purposes;

3. An appraisal of the manner in which you now believe atomic energy can best be utilized, both in the immediate and longer range future, to achieve the objective of advancing science and technology, of raising the standards of living of peoples everywhere, and of improving the climate for international cooperation.

It would be most helpful if the information requested in paragraph 1 above * * * could be formulated on the same bases as the data contained in the new U.S. AEC Ten-Year Program, described in the address by Dr. Frank Pittman on November 3, 1959, a copy of which is enclosed.

Of course, all of the information, analyses, and recommendations in this study will be openly available as a basis for our mutual consideration upon its completion in June 1968. We look forward to a close cooperation with the Authority to the end that atomic energy and all science and technology make the maximum contribution to peace and human welfare. Mr. McKinney and his staff are, of course, available to discuss any aspects of our request with you or your staff at your convenience.

EXCERPT FROM A LETTER TO SENATOR ANDERSON, CHAIRMAN, JCAE, FROM LORD PLOWDEN, UKAEA

Thank you for your letter of 20th November about the review of international atomic policies and programmes to be carried out by Mr. Robert McKinney.

The Authority will certainly endeavour to produce statements for Mr. McKinney on the subjects listed in your letter. I am afraid, however, that owing to the different circumstances in this country, it will probably not be practicable to prepare the data requested on the first subject in the form of the new U.S.A.E.C. ten-year programme.

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REPLY TO SENATOR ANDERSON'S REQUEST ON BEHALF OF MR. ROBERT McKINNEY FOR A STATEMENT OF THE AUTHORITY'S VIEWS ON THE PRESENT AND PROSPECTIVE STATE OF CIVILIAN ATOMIC POWER IN THE U.K.

I. INTRODUCTORY

1. The Atomic Energy Authority derive their powers primarily from the A.E.A. Act of 1954. Under this Act, the Authority can produce, use, and dispose of atomic energy and radioactive substances and conduct all forms of research concerning them. In view of the

terms of Senator Anderson's request, this note is primarily concerned with nuclear power, but the following section deals briefly with the isotope activities of the Authority.

II. ISOTOPES

2. The Radiochemical Centre at Amersham is the branch of the Authority responsible for producing and marketing radioisotopes. It relies for irradiation facilities mainly on the research reactors at Harwell and the plutonium production reactors at Calder Hall. In the future, the Chapelcross production reactors and the electricity boards' power stations should become available for isotope production. The spent fuel of these reactors can also be used as a source of commercial radioisotopes: for example, Caesium–137 has been separated from the waste from irradiated fuel processing in a pilot plant at Windscale. Research into the uses of radioisotopes is carried out mainly by a separate Division at A.E.A.'s research establishments at Harwell and Wantage.

3. In 1958/59, the A.E.A. sold isotopes to the value of £800,000. This was almost twice the figure of 1954/55; the proportion of consignments exported rose from 36% to 60% over the same period.

4. At present the industrial uses of radioisotopes are expanding more rapidly than their uses in the medical field, and there has been a start to the large scale application of radioisotopes in industry: the Authority have supplied 150,000 curies of Cobalt 60 for an Australian plant designed to sterilize animal fibres against anthrax. Other current industrial uses are in thickness gauging, gamma radiography with Caesium and Cobalt sources and oilwell logging.

5. It is as yet impossible to predict how widespread the use of isotopes will become, especially as in a number of applications, there will be alternatives to radioisotopes available. But we are as yet in the infancy of the application of radioisotopes to industrial uses, especially to large scale projects, and demand could grow rapidly.

III. NUCLEAR POWER

(*i*) *The Role of the Authority*

6. The Authority's principal activities in support of the U.K. nuclear power programme are:

(i) the conduct and coordination of research and development, including where necessary the construction and operation of reactor experiments and prototype reactors;
(ii) procurement and processing of feed materials;
(iii) production of fissile materials;
(iv) production of fuel elements;
(v) processing of irradiated fuel;
(vi) consultant services to the Generating Boards and the consortia (see below).

The Generating Boards own and operate the power stations and dispose of the electricity from them to the Area Boards responsible for distribution. The groups of private enterprises known as the consortia are responsible for the construction of complete power stations.

7. Under this division of responsibility the Authority's views on comparative costs and trends are, of course, not to be regarded as definitive: in some important aspects the primary responsibility belongs to the Generating Boards.

(*ii*) *Nuclear Power Stations under construction*

8. The nuclear power stations now under construction for the U.K. Electricity Generating Boards are as follows:

TABLE 1

	Bradwell	Berkeley	Hunterston	Hinkley Point	Trawsfynydd
Electrical output MW	300	275	300	500	500
Specific power (MWE/Tonne of contained uranium)	0.63	0.55	0.60	0.67	0.89
Date first reactor on power	1961	1961	1961	1962	1963

Tenders have been invited for a 500 MW station at Dungeness.

9. These stations all have two gas-cooled graphite moderated reactors fuelled with natural uranium canned in magnox (a magnesium alloy containing beryllium). This reactor system was chosen for the first stage of the U.K. nuclear power programme for a number of reasons: it did not require enriched uranium supplies, it was relatively straightforward in design and construction, and it was the system on which U.K. reactor technology was largely based when the nuclear power programme was launched.

(*iii*) *Costs of the present stations*

10. Until the stations now under construction for the electricity boards have been completed and running for some time, the cost of electricity generated at them can only be estimated. The capital costs of these stations are known within a relatively close margin because the stations are being constructed by the consortia on fixed price contracts subject only to cost variation clauses and correction for any variations in design. There is more uncertainty about fuel costs per unit sent out because of the difficulty of forecasting the precise irradiations which will be achieved as successive improvements are made in the design of the uranium fuel elements. There is also some uncertainty as to the precise load factors at which these stations will operate. In all current estimates the figure of 75% has been adopted. This is less than is being achieved in conventional stations, and may well be exceeded in nuclear stations: if so, current cost forecasts penalise these stations excessively. However, it is considered prudent to adopt a conservative figure at this stage.

Capital Costs

11. Capital costs per kW have declined appreciably for successive stations. The first two stations cost about £155 ($738) per kW output capacity (excluding the cost of the initial charge) costs for a station of the latest design are between £120 ($336) and £130 ($364).

12. This reduction in capital costs per kW has been achieved mainly

by improvements in engineering design. While the size of the spherical pressure vessels in the Hinkley Point reactors is virtually the same as that at Bradwell and Huntersten, the weight of fuel contained in them is about 50% greater. At the same time, by designing the pressure vessel to withstand higher operating pressures, it has been possible to increase the rate of heat removal per ton of fuel. Since a considerable part of the capital cost of the reactor is dependent on the diameter of its pressure vessel, these improvements have had an appreciable effect on the cost per kW. In addition at Trawsfynydd a rather higher gas outlet temperature and improved turbine efficiency have improved the overall efficiency of the station. This reactor will be using 3½" plate for the pressure vessel as compared with the 3" plate used in the first four stations.

Fuel costs

13. Fuel inventory costs will depend on the cost of fuel per tonne and the heat rating in MW(H) per tonne. The prices of the magnox canned natural uranium fuel elements which the U.K.A.E.A. are supplying for these stations are the subject of negotiation with the electricity boards and vary with the design of the element, but they will be about £20,000 per tonne of uranium. Heat ratings have risen appreciably since the first stations were designed and are now in the region of 3 MW(H) per tonne.

14. It is considered that the useful life of the present designs of fuel element should be about 3,000 MWD/tonne. It will, however, be some time before fuel will have been tested to this irradiation as part of the Authority's irradiation programme. The precise fuel cycles to be adopted in the first stations will have to be determined in the light of current experience and cannot be forecast precisely in advance: to estimate fuel replacement costs it has been assumed that fuel will be irradiated to 3,000 MWD/T. The repurchase price of irradiated fuel will be negotiated with the electricity boards, but the standard repurchase price for fuel irradiated to 3,000 MWD/T will be £5,000 per tonne uranium.

Costs per unit

15. The annual capital charges on the stations reflect the rate of interest paid by the electricity boards and the probable life of the station. The rate of interest is here taken as 5½ percent and the cost of the station is amortised over 20 years, giving annual capital charges of 8.36 percent. The first nuclear stations will operate on base load and generating costs are calculated for a 75 percent load factor.

16. On this basis generating costs at a typical up-to-date nuclear station are expected to be between 0.65 and 0.70d (7.6 to 8.2 mills) per kWh. A breakdown of generating costs for such a station is shown in table 2 below.

17. These estimates of generating costs at nuclear stations compare with estimated costs for the most up-to-date coal fired stations now being planned varying from 0.50d. for stations situated near coalfields to 0.65d per kWh for stations remote from the coalfields.

TABLE 2.—*Costs for a typical British nuclear station of recent design*

Assumptions	
Capital Cost	£125/kW.
Heat rating	3.1 MW(H)/T.U.
Thermal efficiency	28.8 per cent
Initial cost of fuel	£20,000/T.U.
Credit for irradiated fuel	£5,000/T.U.
Irradiation	3,000 MWD/T
Rate of interest	5½ percent
Life of plant	20 years

	Generating costs at 75 percent load factor	
	Pence per kilowatt-hour	Mills per kilowatt-hour
Capital charges	0.38	4.6
Fuel inventory	0.07	0.8
Fuel replacement	0.17	2.1
Operating costs	0.05	0.6
Total generating costs	0.67	8.1

(*iv*) *Technical Developments in Nuclear Power*

18. Before proceeding to describe the further developments being undertaken by the Authority in the field of power reactors it may be helpful to quote the general objectives of the programme, as described in the Authority's Fifth Annual Report (1958–59):

"The first aim of the Authority's work on reactor development has continued to be that of ensuring the successful construction and operation of the first nuclear power stations now under construction for the electricity boards in this country. Apart from this immediate task the Authority are devoting extensive resources to the development of more advanced types of reactor, the aim of which is to provide progressively cheaper sources of nuclear power."

"Because of their low fuel costs, nuclear power stations will be operated at the highest load factors possible in the generating system. The effect of the high capital costs of the early stations will thus be minimised by the fact that they will be operated on the base load. Reductions in capital costs will be essential if nuclear stations are to be competitive at the lower load factors that will eventually obtain when the amount of nuclear capacity installed exceeds the base load on the electricity generating system. Hence the achievement of lower capital costs is a major objective of the Authority's programme of reactor development. Although experience in designing and constructing stations using magnox canned natural uranium fuel elements is reducing the capital cost per kW of this type of station, further major reductions will depend on the development of the more advanced reactors."

"To these considerations must be added the need to base plans as far as possible on the use of materials readily and cheaply available. Production of uranium enriched in the 235 isotope is expensive in the United Kingdom. Therefore, the enrichment of fuel, where essential, must be kept low and efforts are being made to develop ways

of using as fuel the plutonium that will gradually become available from the buring of uranium in the early stations."

"Beyond the natural uranium reactors, two stages of development are envisaged. The first is represented by systems attaining lower capital cost by the use of slightly enriched fuel. These are the advanced gas-cooled reactor and the water-moderated reactors. The second aim is to introduce reactors which, besides having low capital costs, have negligible net fissile fuel consumption, i.e., reactors in which the production of fissile materials approaches or exceeds its consumption, and the fuel costs of which are low. The high temperature gas-cooled reactor and the fast breeder reactor are in this category."

As regards the last paragraph of this extract, it should be emphasised that the phrase "water-moderated reactors" includes systems using heavy water moderation: and that the full development potential of the H.T.G.C. is likely to be realised only when it is operated on the U233/Thorium cycle. (See paragraph 26 below.)

19. Whilst the Authority keep under review the whole field of possible developments in reactor technology and reactor systems, their major development effort is at present concentrated on the relatively small number of items described below. In particular, the development of the graphite-moderated gas-cooled technology which was used in the Calder Hall type of reactor continues in the three stages described immediately below.

Reactors currently under construction for the Generating Boards (Magnox)

20. The magnox reactors are a direct development of the Calder Hall design incorporating various improvements in such features as the type of fuel element used, the gas circulating system and the pressure shell. In the development of the stations referred to in paragraph 8 above the specific power has been increased from .55 MW(E) per tonne uranium at Berkeley to .89 at Trawsfynydd and some further improvement may be expected.

21. However, there is a limit to the further reduction in capital and running costs that can be expected from increases in specific power or fuel rating. Despite the accumulation of engineering know-how, the reactor remains relatively expensive to construct, and the capital cost per kilowatt of capacity is correspondingly high. The stations are therefore essentially base-load stations, and it is shown later that even allowing for future reductions in the cost of natural uranium, their competitive position against fossil-fuelled stations is likely to be marginal.

The Advanced Graphite Reactor (A.G.R.)

22. In order to improve the performance of the graphite-moderated carbon-dioxide cooled system, the main essential is to increase the specific power and the fuel rating. This is possible if the temperature of the cooling gas can be raised, but to achieve this end a new type of fuel is required. The limit of gas outlet temperature with a magnox reactor is about 400° C. and to exceed this, it is necessary to alter both the fuel and the can. The A.G.R. therefore uses oxide fuel and both beryllium and stainless steel are being studied as alternative canning materials. Having made these changes, it is necessary to use enriched

fuel between 1 percent, and 2 percent, enrichment depending on the choice of canning material and the design of can. By these means it is expected that the gas outlet temperatures which will be achieved in commercial stations of this type will reach between 525° and 575° C.

23. Of a number of aspects of the A.G.R. study in progress, those receiving particular attention are the behaviour of beryllium-clad elements under irradiation, the effects of the build-up of plutonium in the reactor, and the interaction between graphite and carbon-dioxide under operating conditions. The fabrication of fuel cans from beryllium has proceeded satisfactorily, but their performance under irradiation can be confirmed only by large scale statistical tests which will not yield results for some years yet. Steel cans have been successfully used with uranium oxide in other countries; work in the U.K. includes determination of the optimum balance between the thickness of the can, the corresponding fuel burn-up to be expected, and the necessary resultant degree of enrichment. Work is proceeding on two problems arising from the build-up of plutonium: that of the effects of temperature transients, including the effects of a positive moderator temperature coefficient and that of changes in reactivity due to the formation of the higher isotopes of plutonium. Preliminary experimental results relating to the interaction of carbon dioxide and graphite are encouraging.

24. An experimental reactor of this type (100 MW(H)) is under construction at Windscale and is due to be completed by the middle of 1961. It is expected that commercial stations will come into operation soon after the middle of the decade.

The High Temperature Gas Cooled Reactor (H.T.G.C.)

25. An experimental version of this type of reactor will be built at Winfrith Heath in Dorset by the Dragon project, in which the U.K. is participating jointly with the OEEC. This experiment will be 20 MW(H).

26. The object of H.T.G.C. development is to achieve still higher temperatures using gas cooling and a graphite moderator For this purpose graphite is being developed as a canning and structural material. The fuel will be more highly enriched than in the A.G.R. and will be dispersed in the graphite moderator. This mixture will be canned in impermeable graphite. By this means it should be possible to achieve a system with good neutron economy operating at gas outlet temperatures about 750° C. with correspondingly high thermal efficiency. The system will initially be loaded with U235 as the fissile material, and with thorium as the fertile material, U233 being introduced as supplies permit. Operated in this way, the conversion factor would be high.

27. An important feature in the development is to study the possibility of producing graphite cans which will provide an adequate barrier preventing fission product diffusion into the coolant stream, thus avoiding a highly active primary coolant circuit.

28. In addition to the high thermal efficiencies associated with high gas outlet temperatures, the high operating temperatures and good eat transfer characteristics associated with the "homogeneous" type of fuel should give high heat ratings and correspondingly low capital costs. Furthermore, the compactness of the system and the possibility

of using the coolant gas directly suggest possible applications in addition to land-based generation (e.g., for propulsion).

29. It is thought that reactors of this type and of the fast breeder type described below, could be available for commercial power generation in the United Kingdom early in the next decade.

Fast Breeder Reactor

30. The highly enriched fuel of the fast breeder reactor results in a highly compact core with power densities of the order of 200 kW per litre. It is intended that the system should be fuelled with the plutonium which will in the next decade become available from earlier systems. For initial experimental purposes it is possible to use U235.

31. The system holds out considerable promise of a reduction in electricity costs in the early 1970s. Although work on it was started when it was thought uranium would be scarce and costly, its continued development is justified by potentially low capital and fuel costs.

32. Capital costs might be increased by intricacy of design and the possible need for extra engineering or dilution of the core for safety reasons. Nevertheless, low capital cost should be ensured by the compactness of the reactor and the high heat transfer efficiency of sodium as a coolant.

33. Equally, it is hoped that fuel costs will also be low. A range of fuel is being studied; at present oxides and carbides are receiving particular attention. A good plutonium breeding ratio should be possible; the plutonium credit should thus offset the cost of fuel recovery and reprocessing, and of holding a considerable inventory of fissile material. A burn-up of 2 percent is a first objective for the prototype reactor described below, though limits are imposed by fuel element design for use in the confined core.

34. The Authority have designed and constructed a U235-fuelled fast reactor experiment at their experimental establishment at Dounreay on the north coast of Scotland. This reactor is now operating; its usefulness will be increased in the spring of 1960 by rearranging its core to take fuel element subassemblies for test purposes.

35. The Dounreay experimental reactor has a potential heat output of 60 MW. Considerable further development will be necessary, however, before a full prototype is constructed. An extended programme of experimental physics and of work on the development of reactor materials and fuel elements able to stand the high ratings involved in this system will be required. It will also be necessary to provide for a special study of the degree of fuel enrichment and the prototype may have provision for accepting successive cores at increasing enrichments. This will facilitate study of the problems of heat removal, fuel reprocessing, safety, and control.

Other Systems for Land-Based Power Generation

36. At present the Authority's development effort in the field of land-based power generation takes the form of the four systems described immediately above and therefore covers the gas-cooled graphite moderated technology and the fast breeder reactor technology. The Authority are still considering whether to add to their general study of other systems a particular development in the field of water

moderation. For this purpose they are making a special study of a system based on heavy or light water moderation (or a combination of the two) with steam cooling. Pressure tube designs are receiving particular attention. The potentialities of the B.W.R. are also being kept under review.

Marine Propulsion

37. No marine propulsion reactor has yet been built in the United Kingdom. The Admiralty have, however, ordered a copy of the U.S Skipjack submarine reactor to be supplied to the design of Westinghouse for fitting in the Dreadnaught submarine.

38. The Government have made a study of the possible systems for use in commercial marine propulsion, as a result of which they have invited tenders for a nuclear reactor for a 65,000 ton deadweight tanker based either on the Boiling Water or the Organic Liquid Moderated system. It is recognized, however, that there will have to be considerable developments to reduce the capital and running costs (especially the former) of nuclear powered surface ships before they are economic in other than highly specialised functions.

39. The Government have also studied the problem of safety in nuclear merchant ships and concluded that the problems although considerable, should be capable of solution.

* * * * * * *

Future Nuclear Power Costs

41. The costs of the magnox system described in Table 2 above are likely to be further reduced in two ways. With experience in design and construction and possible improvements in heat transfer, the capital costs should fall by another £10–£20 per kilowatt. Fuel costs will be reduced appreciably when, as expected, the price of uranium falls and the fall is reflected in fuel element prices. The total effect of these improvements may bring generating costs in advanced magnox stations down to about .55d. (6.5 mills)/kWh at 75 percent, load factor. These figures should be compared with the range of 0.50/0.65d./kWh for the coal-fired stations already being planned (see paragraph 17 above).

42. The advanced graphite reactor is expected initially to have capital costs between £80 and £90 per kilowatt with further reductions to be expected. This, and further improvements and the higher working temperature of this system, are expected to bring the generating costs at 75 percent load factor into the region of .5d. (just under 6 mills)/kWh.

43. If a water moderated system is developed, it must have generating costs at least of the same order as those of the A.G.R. for the development to be worthwhile.

44. It is not yet possible to make any prediction about generating costs for commercial stations using the fast reactor or the H.T.G.C. reactor, although these systems are expected to show a significant improvement on the earlier types mentioned. The long term objective as regards future nuclear power costs in the U.K. can be described as the achievement of generating costs in land-based stations substantially below .5d./kWh at declining load factors.

26th January, 1960.

EXCERPT FROM LETTER BY THE REVIEW STAFF TO THE SECRETARY, UKAEA

* * * * * * *

It would be quite helpful to our understanding of the costs shown if you could furnish us with the rate of interest, amortization period, load factor, capital charge in mills per KWH, fuel costs in mills per KWH and operating costs in mills per KWH for the conventional plants referred to in paragraph 41. You will appreciate that we wish to understand more fully the comparison which you have drawn.

* * * * * * *

REPLY BY THE SECRETARY, UKAEA

In your letter of March 1st you asked for further information about the costs of conventional plants referred to in para. 41 of the first part of the Authority's reply to Senator Anderson's letter of November 20th.

I hope that the following figures will be of assistance: you will realise that they represent forecasts of what advanced plant at present under construction will achieve rather than results based on experience.

Rate of interest	percent	5½
Amortization period	years	30
Load factor	percent	75
		Mills per kWh
Capital charges		1.2–1.4
Fuel costs		4.0–5.6
Operating costs		0.6–0.6
		5.8–7.6
i.e. (d per kWh)		0.50–0.65

* * * * * * *

STAFF NOTE.—The Soviet Union was requested to furnish information concerning its atomic power program, and its thoughts on the appropriate utilization of atomic power as an instrument in advancing worldwide standards of living. No information was forthcoming; correspondence with the Soviet Union appears below.

TEXT OF A LETTER FROM SENATOR ANDERSON TO TO V. S. EMELYANOV

Professor V. S. EMELYANOV,
Head of the Chief Directorate for the Utilization of Atomic Energy of the U.S.S.R.

DEAR PROFESSOR EMELYANOV: As you know, I have appointed Mr. Robert McKinney, former U.S. Representative to the International Atomic Energy Agency, to undertake a review and appraisal, and to submit recommendations concerning the role of atomic energy in international affairs. I understand that Mr. McKinney discussed the undertaking with you in Moscow on September 29, 1959, and

that you felt that close cooperation and exchange of information between the United States and the Soviet Union on peaceful atomic programs would be very desirable.

In the interest of furthering this informal cooperation, I would like to request that you undertake to furnish to Mr. McKinney by the early part of next year—hopefully by February 1960—the following information and expressions of view:

1. A statement of the present and prospective state of technology in the U.S.S.R. of the various peaceful applications of atomic energy, with special emphasis on civilian atomic power. This would include details of present and prospective construction and operating costs both for conventional and atomic powerplants.

2. An appraisal of the manner in which atomic energy can best be utilized, both in the immediate and longer range future, to achieve the objectives of advancing science and technology, of raising the standards of living of peoples everywhere, and of improving the climate for international cooperation.

It would be most helpful if the information requested in paragraph 1 above could be formulated on the same bases as the data contained in the new U.S. AEC Ten-Year Program, described in the address by Dr. Frank Pittman on November 3. I am enclosing for your information a copy of Dr. Pittman's speech, together with a copy of Mr. McKinney's talk on that same date outlining the study for the Joint Committee on Atomic Energy.

I am addressing similar requests for assistance to other countries and to various regional and international organizations of which the United States is a member or participant. * * *

Of course, all of the information, analyses and recommendations in this study will be openly available as a basis of our mutual consideration upon its completion in June 1960. We look forward with pleasure to this informal cooperation which could be a truly significant contribution to peace and human welfare through science and technology.

TEXT OF SECOND LETTER TO PROFESSOR EMELYANOV

On November 12, 1959, I wrote requesting your cooperation in setting forth a comprehensive statement of the present and prospective status of technology in the Soviet Union relating to atoms-for-peace, Soviet plans for international atoms-for-peace cooperation, your view of prospective relative economics for atomic power, and suggestions concerning ways to utilize atomic energy most effectively for the betterment of mankind. This request, which I had discussed with you in advance during your October visit to the Los Alamos Scientific Laboratory, was made in connection with the review of international atomic policies and programs of the United States being conducted for the Joint Committee by Mr. Robert McKinney, with whom you are acquainted through your common service on the

Board of Governors of the International Atomic Energy Agency in Vienna.

I understand that Mr. McKinney also discussed the request with you, and that his colleagues in the study, Messrs. Hamilton and Miller, discussed it with you during their meeting with you in Vienna on January 16.

The report on the review will be completed by the end of May and the background papers submitted by various public and private organizations in the United States and other countries will be assembled and printed about May 15. Even last minute additions of material, submitted too late to be of substantive value in reaching review conclusions, cannot be incorporated after approximately May 20.

I therefore hope that we may receive your reply so that the accomplishments, contributions, and views of the Soviet Union may be reflected as you would desire them to be in our report volumes.

A copy of my letter of November 12, 1959, is enclosed.

TEXT OF SOVIET UNION NOTE TO THE DEPARTMENT OF STATE

[Embossed Seal of the USSR]
Embassy of the Union of
Soviet Socialist Republics
No. 56–N

In connection with the notes dated December 24, 1959, and April 26, 1960, from the Department of State of the USA, the Embassy of the USSR is sending herewith a report by V. S. Yemelyanov, Chief of the Main Administration on the Use of Atomic Energy at the Council of Ministers of the USSR, concerning the future of atomic power in the USSR, which was presented at the 2d International Conference on the UN on the Peaceful Use of Atomic Energy, for transmission to Senator Clinton P. Anderson, Chairman of the Joint Congressional Committee on Atomic Energy. It is not possible to comply with Senator Clinton P. Anderson's request for data on the ordinary power resources of the Soviet Union with a forecast for the future, isasmuch as there is at present no generalized published data on this question.

Enclosures: the report by V. S. Yemelyanov entitled "The Future of Atomic Power in the USSR."

WASHINGTON, MAY 6, 1960.

[Initialed]
Department of State,
United States of America,
Washington, D.C.

EDITOR'S NOTE.—The enclosure was the Russian text of a speech previously published in English in the proceedings of the 1958 United Nations Conference on the Peaceful Uses of Atomic Energy at Geneva.

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STAFF NOTE.--The following summary report, "The Atomic Energy Programs of Communist Countries," was prepared by the review staff from public documents.

THE ATOMIC ENERGY PROGRAMS OF COMMUNIST COUNTRIES

Following the successful operation of the five megawatt "First Atomic Power Station" at Obninsk in the Soviet Union on June 27, 1954, there was a great deal of optimism and speculation regarding the future benefits to be derived for mankind from the use of the atom. Both technical and non-technical officials of the government gave very optimistic predictions as to the use of this new form of energy for various purposes. The subsequent revelations of progress in nuclear technology by eastern and western scientists at the Geneva Conference of 1955 gave impetus to further optimistic prediction on the role of the atom in the nation's economy. As a result, when Soviet national economic planners were preparing the new Five Year Plan (1956-1960), they were greatly influenced toward assigning to this new source of energy the target of installing 2 to 2½ million electrical kilowatts generating capacity by 1960. In 1957 a reappraisal of this target resulted in an extension of the goal as part of a new Seven Year Plan. More recent reappraisals describe the atomic energy effort more as a research and development effort, but recognize the great potential of its use for accomplishing more distant economic goals.

A. The National Economy and the Need for Energy

Within the framework of a centralized authority, the Government of the Union of Soviet Socialist Republics directs the economic planning

and development of its fifteen Union republics through an organ of the Council of Ministers known as the State Planning Commission, or GOSPLAN. Since 1957 when a partial decentralization of economic control occurred, the economic planning of the country has been carried out by Economic Councils of the 105 administrative districts of the Soviet Union, which are responsible for all industries in their respective areas and submit their plans to the State Planning Commission for approval and coordination. Assisting the Economic Council is an Advisory Board, made up of prominent persons representing the principal groups of the economy. A Board of Power is in charge of all power plants in the areas.

In addition to the State Planning Commission, two additional offices of the Council of Ministers are concerned with the planning function for the national economy, viz., the Scientific and Technical Committee, which determines the techniques to be used in the economy, and the State Committee on Construction, which acts as a coordinating body for all designing, engineering and development of national construction interest.

1. <u>The Seven Year Plan (1959-1965)</u>.

In 1957 the Soviet Government became dissatisfied with its Five Year Plan of 1956-1960 and abandoned it in favor of a new Seven Year Plan for the years 1959 to 1965 for the entire national economy. Two of the areas of dissatisfaction appear to have been the lack of sufficient

progress with the general economic development of certain republics and with certain specific areas of the economy, such as power development.

In discussing the tasks of the Seven Year Plan, Pravda, the party organ, pointed out that

> "The Communist Party wishes to gain time in peaceful economic competition with the most highly developed capitalist countries and envisages maximum acceleration of the development of the economy especially of the decisive branches of production."

One of the most urgent tasks of the Seven Year Plan is to develop a basis for the most economic and effective exploitation of the abundant sources of power available, including atomic energy. Proper development of such a fuel balance is expected to enable the U.S.S.R. to achieve at the earliest date possible Lenin's dream of an electrification of the national economy.

The present Seven Year Plan calls for the installation by 1965 of 112.0 million kilowatts of electric power capabity, which is double the 1958 capacity, and the production of between 470 and 480 billion kilowatt hours of electricity, as compared with a 1958 production of 245* billion kilowatt hours. (The U.S. produced 724 billion kilowatt hours in 1958 and expects to produce 1150 billion kilowatt hours in 1965.)

Of the total production of 218.9 billion kilowatt hours of

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* The 245 billion kilowatt hours includes consumption by the power stations; total net production was 218.9 billion kwh.

electricity in 1958, 78% of it was produced by thermal stations and 21% by hydroelectric stations. Thermal station production is expected to rise in 1960 to 80% of the total production, emphasizing the relative importance of thermal over hydroelectric power stations. In making this determination, the lower cost of the thermal stations and less time required in their construction were the dominant factors.

In a discussion of the electrification of the national economy, Khrushchev reportedly told an "All Union Conference on Power Construction" on November 28, 1959:

> "Confronting us is the task of drafting the Party's program for consideration at the next regular Party Congress, the 22nd, to be held in 1961. The main problems in our Party's program should be 1) electrification, 2) construction of high capacity power transmission systems and creation of material and technical base for communism. Electrification ensures the wide scale mechanism and automation in production, thus establishing a prerequisite for transition to communist labor and to a communist society. The long range plan for electrification of our country in the next 15-20 years and the long range plan for development of the national economy during the same period must become the central pivot of our program for building communism."

In order to determine the feasibility of electrifying the country in the next 15-20 years, that is to meet fully the needs of all branches of the national economy, Khrushchev held an informal meeting on the Black Sea Coast in mid-November 1959 with four of his top power plant advisors.

Reporting on the results of the meeting, Khrushchev stated:

"If these needs are to be met and most satisfactory rates of power development ensured, power generation in 1970 must amount to 900 billion kwh, in 1975 to approximately 1500 billion kwh, and in 1980 to approximately 2300 billion kwh meaning that power plant capacity must be increased about seven or eight-fold in the space of 15-20 years.

"This rapid rate of growth can only be realized by building thermal power plants of 2.4 million kwh capacity and more, operating on cheap varieties of coal, oil and gas and equipped with turbogenerators of 300,000 kw and above and also by building highly economic hydroelectric stations of up to 5 to 6 million kw with generating units of 500,000 kw each."

2. Conventional Fuel Resources

With regard to conventional fuel resources, a comparison of the two tables below, showing figures of production for 1958 and production targets for 1965, indicates the proposed sharp increase in output of petroleum and natural gas and the anticipated decline in the production of other conventional fuels.

	1958		1965	
Commodity	Output (Million metric tons standard fuel)*	Percent of total output	Output (Million metric tons standard fuel)	Percent of total output
Coal	365.2	58.1	439.2	41.8
Petroleum	161.9	25.7	343.2	32.7
Natural Gas and Associated Gas	33.7	5.4	177.9	17.0
Peat	20.0	3.2	27.0	2.6
Fuelwood (Excluding Losses)	24.9	4.0	25.7	2.4
Combustible Shale	4.5	0.7	7.5	0.7
Hydroelectricity	18.2	2.9	29.5	2.8
	628.4	100.0	1050.0	100.0

* "Standard fuel" has a calorific value of 7,000 kilocalories per kilogram.

It will be noted from the above that the projected oil and gas increases will represent almost 50% of the total output in 1965.

In a document published recently by the European Atomic Energy Community, entitled "Outlook for the Development of Nuclear Energy,"* the following information on the USSR is reported:

> "... It is the Russian opinion, in relation to the development of other sources of energy, that oil and gas are new means toward higher productivity... Within a few years oil exports will have increased by 30 million tons, exports of oil to the free world in 1959 already being 13 million tons."
>
> "... Oil has recently been discovered in Uzbekistan, Turkmenia (new Middle East, according to Minister Antrapov), Siberia, Irkutsk and Berezhovo, with promising geological similarity along the Lower Volga."
>
> "... New 4000 km pipelines from the Urals with branches to Poland, Eastern Germany, Hungary, Czechoslovakia, with a flow of 15 million tons annually, and four refineries of one to four million tons annual capacity are expected to be completed in four years, i.e., before the end of 1963... Two new oil ports are to be built at Klaipeda, Lithuania, and at Ventspils, Latvia, to serve the Baltic..."

A more detailed discussion of the energy resources of the Soviet Union is contained in the Energy section of this report.

B. The Soviet Atomic Energy Program

1. Historical Development of the Program

Research on the basic structure of the atom and its nucleus in

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* Document "EUR/C/37/a/60e, dated 3 May 1960, Brussels."

the Soviet Union started about the same time as work in other leading countries of Europe. The work of Soviet scientists in foreign laboratories, such as Peter Kapitsa on alpha particles in the laboratory of Lord Rutherford of England, and V. I. Vernadskii at the Radium Institute with Madame Curie in Paris and other Western European laboratories during the early 1920's enabled Soviet scientists to keep abreast of nuclear research by their Western counterparts. The Radium Institute at Leningrad, which was founded by Vernadskii in 1922, developed into a first class laboratory, including among its equipment the first cyclotron in Europe, which went into operation on a limited basis in 1937. From the early 20's until the German invasion of the USSR in July 1941, Soviet scientists, such as A. F. Ioffe, Y. I. Frenkel, L. D. Landau, I. V. Kurchatov, D. V. Skobeltsyn, Y. B. Khariton and Y. B. Zeldovich, as well as Kapitsa and Vernadskii, were doing important theoretical and experimental research which was contributing appreciably to a better understanding of the atom and its nucleus. Early recognition of the importance of this new field of science by Soviet scientists is evident.

A "Special Committee for the Problem of Uranium" was established under the Praesidium of the Soviet Academy of Sciences in the spring of 1940 to undertake a program of research on uranium, including the development of processes for isotope separation and the control of a chain reaction. Uranium prospecting was also provided for by a State

Fund for Uranium Metal. These activities occurred about the same time that the United States was looking into the same problems, prior to its establishment of the Manhattan Project.

The energetic execution of this program was underway in the U.S.S.R. by June 1941, when the German invasion occurred, and Soviet scientists were transferred from the nuclear research programs to other defense projects in other parts of the country. For some reason, nuclear research, which might have led to the earlier development of an atomic bomb by the U.S.S.R., was apparently not given the same degree of priority as other military projects and was set aside.

After the withdrawal of the German Army began, following the battle for Stalingrad in the spring of 1943, Soviet scientists gradually returned to their laboratories in the western part of the country. Although nuclear research was renewed shortly thereafter by Kurchatov, Kapitsa, Frenkel and others under the general direction of the Academy of Sciences, and later the People's Commissariat of Munitions, the program continued on a small scale for the succeeding three years.

At the end of World War II, the Soviet Government organized their atomic energy effort on an urgent, full-scale basis, with direction of the program being transferred from the Ministry of Agricultural Machine Building (Munitions Ministry) to a newly established office of the Council of Ministers, known as the First Chief Directorate. General Boris L. Vannikov, who was in charge of the atomic energy project in the former

organization, continued to administer the project with the new office.

Soviet Foreign Minister V. M. Molotov stated in November 1947 that the secret of the atomic bomb no longer existed. There was no public evidence of the Soviet Union's knowledge of nuclear weapons technology, however, until the U.S.S.R. detonated a nuclear device in August 1949. During the next four years, work not only was continued on the development of nuclear weapons technology, but also was commenced on the development of a weapon using fusion (thermonuclear) energy. A change in the administration of the atomic energy program occurred on June 26, 1953, coincidental with the arrest of Lavrenti Beria, head of the Soviet secret police and superior of General Vannikov. The management level of the program was raised from a directorate and became the "Ministry of Medium Machine Building" under V. A. Malyshev. General Vannikov was demoted to become First Deputy to Malyshev. Two months later, on August 12, 1953, the U.S.S.R. exploded a device which utilized both fission and thermonuclear energy.

Although the Soviet Government was slow in responding to the appeal of President Eisenhower on December 8, 1953, for an international Atoms-for-Peace program which would bring the benefits of the civil uses of atomic energy to other countries, the U.S.S.R. was already undertaking a national program for use of nuclear energy for civil purposes. Radioisotopes for industrial research and other peaceful applications had been utilized in the Soviet Union for many years. Research and development on

nuclear energy for the production of electricity resulted in the construction and operation (on June 27, 1954) of a graphite-moderated reactor capable of generating five megawatts of electricity. The broad scope of the Soviet program, adaptable to peaceful purposes, was later exhibited at the two Geneva Conferences. Growth of the importance of the Soviet program also brought changes in the directing personnel of the program. In February 1955 Malyshev was promoted to a position of greater responsibility and was succeeded by Colonel General A. P. Zavenyagin, who died in 1956. M. G. Pervukhin assumed his responsibilities as Minister of Medium Machine Building after Zavenyagin's death and retained the position until his removal during the period of "anti-state activities" of Malenkov, Molotov and Kaganovich in 1958, although direction of the civil atomic energy program was separated and assigned to a new Main Administration for the Utilization of Atomic Energy under Ye. P. Slavskiy. When Pervukhin was demoted to a less important role, Slavskiy replaced him as Minister of Medium Machine Building. V. S. Yemelyanov succeeded Slavskiy as head of the Main Administration for the Utilization of Atomic Energy.*

Despite the attention given by the Government of the U.S.S.R. to the peaceful uses of atomic energy, including participation in international programs since the first Geneva Conference, the Soviet Union has continued to give primary attention to its military program. In November 1955 a test involving a deliverable hydrogen bomb was conducted.

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* In June 1960 the organization was made a State Committee on Atomic Energy, and Yemelyanov given the rank of a Minister.

The conduct of Soviet missile research has also broadened the potential utilization of nuclear weapons for military purposes.

2. The Atomic Energy Program Today

a. Availability of Source and Other Nuclear Materials

(1) Uranium. Despite declassification of information concerning all aspects of the uranium program of the United States, the Soviet Government has not published any significant information since World War II on the location, production, reserves or other significant data on their uranium resources, limiting discussions at the Geneva Conferences to such data as geological minerals present, their origin, etc.

Because of the estimated scope of the Soviet civil and military program, it is widely believed by most Western observers that the Soviet resources of uranium must also be large. A 1960 estimate of the uranium and thorium ore reserves based upon information published before and after World War II may be considered in the range of 80,000 to 270,000 metric tons of recoverable uranium metal within the USSR and 100,000 to 370,000 metric tons of uranium metal in the Soviet Bloc as a whole, sufficient to meet the needs of a large atomic energy program. It has also been estimated from the same published sources that the entire Soviet Bloc of countries has an annual production of 10,000 to 20,000 metric tons of equivalent uranium metal.

The locations and estimated capacity of the individual reserves are covered in more detail elsewhere in the report, "Review of International Atomic Policies and Programs

of the United States", and entitled "Estimated Soviet and Soviet Bloc Uranium Production and Reserves."

(2) Other Nuclear Materials. With regard to thorium, about which there has been much less information published, the reserves of thorium may be considered in the range of 100,000 tons of ThO_2, if thorium is indeed being produced.

In addition to uranium and thorium resources, the Soviet Union has facilities for the production of uranium-235 for making reactor grade graphite, for the production of plutonium, and for the production of heavy water.

It has been estimated that the USSR began its gaseous diffusion plant in 1947 and has developed it with the assistance of German scientists, such as Manfred von Ardenne and Gustav Hertz, into a very substantial effort, primarily for the military program. Although the Soviet Government is making uranium-235 available to other countries and (50 kilograms) to the International Atomic Energy Agency in Vienna, the total to be transferred under these bilateral agreements represents a relatively small amount, when compared to the amounts that have been allocated for similar purposes by the United States.

Reactor grade graphite has been produced in the U.S.S.R. at least as early as 1947 when the first graphite moderated reactor went into operation. Since that time graphite reactors have been one of the principal types developed in the Soviet Union.

Plutonium has also been produced in the U.S.S.R., at least since

1949. The largest operable power-producing reactor in the U.S.S.R. is presently a dual purpose graphite moderated reactor, capable of producing 100 megawatts of electricity as well as plutonium for the Soviet weapons program. This is one of six reactors scheduled for operation at the undisclosed site in Siberia. In addition to satisfying the needs of the Soviet weapons program, the plutonium from such reactors could be used to service the future requirements of the plutonium-fueled fast breeder reactors.

Heavy water production in the Soviet Union is also considered substantial and has been satisfying the heavy water reactor program since 1949.

With the constantly expanding needs of the atomic energy program, new and additional plants may be expected to be built to produce greater quantities of the foregoing and other materials for both the military and civil program.

b. Present Organization of the Program

In order to understand the organization of atomic energy activities in the U.S.S.R., one must look at them in terms of their relationship to the organization of Soviet science and technology in general. This rather complex relationship involves the U.S.S.R. Academy of Sciences, the U.S.S.R. State Planning Committee, the State Scientific and Technical Committee, various All-Union Committees, ministries and economic councils, and for our purposes, the Main Administration for the Use of Atomic Energy. The actual conduct of research and development

work is carried out by scientific and technical institutes* and industrial organizations. With the 1957 plan of decentralization now in effect, the individual union republics of the U.S.S.R., except the Karelo-Finnish and Moldavian Republics, have their own Academies of Sciences, economic planning committees, scientific and technical committees, ministries, councils and regional institutes for atomic energy.

Overall planning responsibility for the preparation and coordination of future plans for the national economy is under the powerful State Planning Committee. Close coordination of effort is maintained with various ministries and commissions of the national economy, as well as with governmental organs concerned with the administration of the science program.

The U.S.S.R. Academy of Sciences is administered by a Praesidium, which is composed of a dozen of the nation's top scientists, all of whom are Academicians. A. N. Nesmeyanov is the President of the Academy, which has responsibility for the planning, coordination and budgeting for science activities in the USSR as a whole.

The "State Committee on Science and Technology" is an influential organ with advisory responsibilities under the chairmanship of Konstantin D. Petukhov, who also holds the rank of Minister.

In addition to the above governmental bodies which are concerned

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* An institute may vary in size and consist of one or more laboratories.

to various degrees with the formulation of planning and policy development for Soviet science and technology (including atomic energy), there are also several governmental bodies concerned with the direction and administration of the programs.

It was noted in the previous section of this report that in April 1956, in deference to the greater attention required for the peaceful uses of atomic energy, a segment of the responsibilities of the Ministry of Medium Machine Building was split off and assigned to a newly created organization known as the Main Administration for the Use of Atomic Energy. The Ministry of Medium Machine Building, under Ye. P. Slavskiy, continued to be responsible for those activities associated with the military application of atomic energy.

In establishing the Main Administration for Atomic Energy on April 19, 1956, the Soviet Government made the following announcement:

> "In order to promote the wide use of atomic energy in all branches of the USSR's national economy and to further cooperation in the peaceful uses of atomic energy between the USSR and other countries, a Main Administration on the Use of Atomic Energy has been set up under the USSR's Council of Ministers.
>
> "The Main Administration has been entrusted with the development of atomic reactors for power stations and for other electric power installations and with the direction of research work on other means of using atomic energy."

The result of this separation of the civil and military atomic energy programs where possible has enabled a more rapid expansion of the unclassified uses of atomic energy to all fields of the national economy and has enabled the government to provide greater security to

the military aspects, which remain classified.

The present Head of the Atomic Energy Administration is V. S. Yemelyanov, a former metallurgist and a Corresponding Member of the USSR Academy of Science. With the spreading uses of atomic energy to all branches of the economy, the Main Administration is becoming more of a coordinating body. For this reason the organization is a comparatively small body. The functions of the organization are similar to those relating to the civil uses of atomic energy for which the U.S. Atomic Energy Commission are responsible.

A close working relationship exists between the Main Administration for Atomic Energy and other agencies of the Soviet Government who have primary responsibility in other fields, such as the Ministry for Power Plant Construction, the Ministry of Geology and Mineral Resources, the Ministry of Chemical Industry and the Ministry of Heavy Machine Building. In the development of power reactors, the Atomic Energy Administration does the reactor research and engineering work; the Ministry of Power Plant Construction designs and builds the stations and receives the reactor from the nuclear energy program; the Ministry for Medium Machine Building provides the nuclear fuels; and the Ministry of Instruments and Automation develops and installs the instrumentation. The Ministry of Power Plant Construction also operates the station after it produces electricity.

As part of the present Seven Year Plan to decentralize research and development so as better to assist the economic development of less developed areas of the USSR, the Soviet Government, working closely with

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governments of the Union republics, is developing a number of scientific centers in Novosibirsk, Irkutsk, Pushchino and Tbilisi. In addition, existing institutes are expected to be strengthened and new institutes to be established.

Another form of institution playing an important role in atomic energy in the U.S.S.R. are the university and technical colleges. Under the USSR Academy of Sciences such institutions of higher learning are preparing the chemists, physicists and engineers for entry into the atomic field in increasingly larger numbers each year. One of the leading examples of this is the University of Moscow, which has its own nuclear reactor and other important equipment.

c. The Research and Development Program

Recent studies of the atomic energy program of the U.S.S.R. by Western authors have brought out more information on the early recognition by the Soviet Government of the importance of atomic energy and the active program of nuclear research groups at Leningrad and Kharkov from the early 1920's and later at Moscow. Although the program was interrupted by World War II, there is strong evidence that it was re-initiated with great vigor at the end of the war, with the obvious objective of the development of first a chain reaction, and subsequently a military weapon.

The success of the Soviet Government with their atomic energy efforts is now history. As in the United States the development of nuclear and thermonuclear weapons has created an immense atomic energy

complex with large plants, materials and equipment. Thousands of trained and experienced scientists and technicians are engaged in this massive effort.

Exchanges of Soviet experiences with the West has developed a healthy respect for Soviet science. Although the overall Soviet atomic energy program is not believed to be as large as that of the United States, it may be considered as one of the most comprehensive programs in the world. Most observers at the two large atomic energy conferences at Geneva in 1955 and 1958 have voiced the opinion that the United States remains the most advanced nation in research and development work on nuclear fission and fusion. In many cases some observers indicated their feeling that the Soviet atomic energy program was strikingly similar to the U.S. and certain other western programs.

The degree to which Soviet science has depended on foreign sources to assist its program is difficult to evaluate. A report by a U.S. legislative committee studying the post-war espionage trials of Klaus Fuchs, Allan Nunn May and others estimates that the Soviet atomic energy program was advanced by at least eighteen months by such activities. Publication of the official U.S. Government report of the wartime military weapons project saved the Soviet Government additional time and money. The use of German scientists in the Soviet program is also known to have been of assistance, particularly with development of their isotope separation facilities. Finally, technology discussed by Western scientists at the First Geneva Conference of 1955

and other conferences showed up in Soviet papers at the Second Geneva Conference of 1958.

There apparently can be no conclusion drawn from the above as to the actual degree to which the Soviet program has been helped by technology obtained from the West. Soviet government classification standards, restrictions placed by the Government upon the publication of "preprints" of Soviet scientists, plus the time required in translation from Russian into English, limit and delay further the knowledge of Soviet scientific progress by scientists of other countries.

Most knowledgeable Western observers regard Soviet scientists as very competent, serious and dedicated men. Where the Soviet Government has concentrated its efforts, as in the case of "high energy" physics, the resulting work has been very competent and thorough. Use of "task forces" to carry out urgent projects under a centralized direction has enabled the construction of certain types of equipment in very short periods of time. This has enabled Soviet science and technology to make important contributions to the advancement of the economic, political and military objectives of the Government.

(1) Fission Research Reactors. The first nuclear reactor to go into operation in the Soviet Union is reported to have been a low powered natural uranium, graphite-moderated, air-cooled reactor, which went critical sometime in 1948. This

reactor became the forerunner of a series of Soviet reactors based on the "uranium-graphite" concept.

The first Soviet reactor designed for using enriched uranium fuel, as well as light water as a moderator, was the WWR-1,* a zero-energy assembly which achieved criticality sometime in 1949. This was redesigned and operated again in 1951 as the WWR-2. Fueled with approximately 3.5 kilograms of uranium-235 enriched to 10 percent, the WWR-2 has a rated thermal power of 300 kilowatts and a maximum neutron flux of $2 \times 10^{12} n/cm^2/sec$. Several years later when additional space was required, the power level was raised to 3000 kilowatts and the maximum thermal neutron flux increased to $4 \times 10^{13} n/cm^2/sec$. by increasing the fuel load by 30 percent. The reactor is now operable at the Institute for Atomic Energy in Moscow.

Soviet experience with research reactors using heavy water as a moderator began with the design (in 1947) and the initial operation (in 1949) of a CP-5 type of reactor at the Institute of Exploratory and Theoretical Physics in Moscow. The reactor, known as the TR, used heavy water as a moderator and for heat removal. It was designed for a maximum thermal flux of $2 \times 10^{12} n/cm^2/sec$. and was used for physical and biological research and radioisotope production. In 1957, the TR

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* WWR is English equivalent of Russian designation VVR, referring to water-water moderated reactors. TR or TVR designation refers to heavy water moderated reactors. BR abbreviation refers to "fast" neutron reactors.

reactor was reconstructed, which increased the power to 2500 kilowatts and the maximum flux to 2.5 x 10^{13}n/cm^2/sec. Annular 2% enriched fuel elements are now used in the reactor.

Each of the above three reactor concepts -- graphite, heavy water and light water moderated -- formed the basis for the development of larger reactors used for power and propulsion purposes. In addition, several additional research reactors have been constructed for use in the Soviet program.

A reactor known as RPT was put into operation in 1952, which used graphite as a moderator. Using 10% enriched uranium fuel elements initially, the reactor was later reconstructed for use with 90% fuel elements, which saved 12 fuel channels for experimental purposes. By this change the rated power level was raised from 10,000 kilowatts to 15,000-20,000 kilowatts and the maximum flux increased from 8 x 10^{13} to 1.8 x 10^{14}n/cm^2/sec.

A swimming pool research reactor, designated WWR-8, was designed and then operated in 1955 at what is now called the Atomic Energy Institute in Moscow. The reactor has a designated power level of 2000 kilowatts and a thermal neutron flux of 2 x 10^{13}n/cm^2/sec. It is an improved version of the earlier WWR-C and has been developed for use at institutes throughout the USSR and for export to other countries under the terms of bilateral agreements for cooperation. Designed for research and radioisotope production, the reactor uses 4.5 kilograms of uranium-235 enriched to 10 percent as fuel elements, clad in

aluminum. Reactors of this type are now operable in Czechoslovakia, East Germany, Poland, Hungary and Rumania. Similar reactors are under construction for the Academy of Sciences of the Georgian and Latvian Republics.

The Soviet Government has also recently announced the operation of the "WWR-M", a 10,000 kilowatt pool type research reactor, located at the Institute of Physics and Technology at Leningrad. Using uranium oxide elements canned in aluminum alloy, the reactor is to be used for the "production of high specific radioisotopes, production of trans-uranium elements, neutron physics research, and other physical experiments. The maximum thermal flux is $1 \times 10^{14} n/cm^2/sec$. A similar reactor is now operable at Kiev.

A smaller pool-type reactor with a thermal power rating of 1000 to 1700 kilowatts and a maximum neutron flux of $1.2 \times 10^{13} n/cm^2/sec$. has been constructed near Sofia for the Bulgarian Academy of Sciences.

At the second Geneva Conference in 1958, a Soviet delegate described a specialized water moderated research reactor, designated WWR-Z, for radiochemical research. The reactor has a rated power level of 10,000 thermal kilowatts and a neutron flux of $1 \times 10^{14} n/cm^2/sec$.

Soviet research with fast breeder reactors began with the putting into operation in April 1955 of the "BR-1", a low-power reactor experiment. This was followed in 1956 with the operation of the BR-2, a 100 kilowatt fast breeder mercury cooled reactor experiment capable of producing a flux of $1 \times 10^{14} n/cm^2/sec$. Plutonium fuel elements clad

in stainless steel were used. In mid-1957 the BR-1 was rebuilt, the uranium blanket being replaced by a uranium and water lattice and renamed the BR-3. In June of 1958 the fourth fast breeder experiment went critical at Obninsk. Sodium-cooled and using plutonium oxide fuel elements in stainless steel canning, this reactor, designated the BR-5, has a power rating of 5000 thermal kilowatts. Results of the experience with this reactor are expected to assist in the design of larger reactors, capable of producing electricity. All of the four fast breeder reactor experiments have been operated at Obninsk.

Under the terms of agreements for cooperation with Yugoslavia and Red China, the Soviet Government has constructed in each of those countries a 7000 to 10,000 kilowatts, heavy water moderated and cooled research reactor designated the "TVR-S" for research purposes and for radioisotope production. The reactor has a maximum neutron flux of $5.5 \times 10^{13} n/cm^2/sec$.

Two of the most advanced and impressive Soviet research reactors are the super-power (SM) reactor and the pulsed neutron source reactor, both reportedly under construction. The SM reactor is a 50,000 kw pressurized water flux-trap MTR tank type reactor, designed for a maximum thermal flux of 2.2 x 10 n/cm /sec. Under construction for the Laboratory of Neutron Physics in Dubna is the pulsed neutron source reactor. Maximum power was reported to be 10,000 kilowatts and the number of neutrons per burst 10^{17}.

The comprehensive nature of the Soviet research reactor program may be seen from the diverse types of research and test reactors

described above. As in the United States, the Soviet Union is pursuing a research and development program which is intended to derive as broad a reactor technology as possible and lead to an economic and feasible nuclear power reactor. Evidence of Soviet work in this field indicates the intense reactor research underway in the Soviet Union. As the program develops, a focusing on those projects of the most promising types may be expected.

Research and Test Reactors in the USSR

Designation	Location	Type of Moderator	Thermal Power (in Kilowatts)	Flux ($n/cm^2/sec.$)	Date of First Criticality	Comments
			Research Reactors			
PSR	Unstated	Graphite	(10 watts)		1947	
TR	Thermo-technical Laboratory, Moscow	Heavy Water	500	$2x10^{12}$	1949	
VVR-1	Institute for Atomic Energy, Moscow	Light Water	zero e energy		1949	
VVR-2	"	"	300	$2x10^{12}$	1951	
VVR-S	"	"	2000	$2x10^{13}$	1953	Export model
VVR-M	Inst. of Physics and Technology, Leningrad	"	10,000	$1x10^{14}$	1959	
IRT	Physical Institute, Tbilisi	"	2000	$1x10^{13}$	1959	
IRT-2000	Salapils, Latvia	"	2000	$1x10^{13}$		
VVR-M	Kiev	"	10,000	$1x10^{14}$		Similar to Leningrad reactor
BR-1	Obninsk	Fast Breeder	(10 watts)		1955	
BR-2	Obninsk	"	100			
BR-5	Obninsk	"			1958	

In addition to the above, research reactors are reportedly under construction at Tomsk, Sverdlovsk, Tashkent and Minsk.

Designation	Location	Type of Moderator	Thermal Power (in Kilowatts)	Flux ($n/cm^2/sec.$)	Date of First Criticality	Comments
			Test Reactors			
RFT	Inst. for Atomic Energy, Moscow	Graphite	15,000 - 20,000	$1x10^{14}$	1952	Raised to present power and flux in 1958
SM	Undecided	Water Moderated	50,000	$2.2x10^{15}$	1960	
		Water: Beryllium Reflected	150,000		1960	

(2) Nuclear Power Experiments

In June 1954, the "first" power demonstration reactor in the world (later identified as APS) was put into operation at Obninsk, 60 miles from Moscow. The reactor, which was capable of a thermal output of 30,000 kilowatts and the production of 5000 kilowatts of electricity, used uranium enriched up to 5% in the isotope U-235; graphite as a moderator and water under pressure as its coolant.

During the United Nations' First International Conference on the Peaceful Uses of Atomic Energy in August 1955, representatives of the USSR described their reactor program with an appreciable amount of detail. The highlight of the program described was naturally the APS reactor. In addition, however, Soviet scientists described their work with heavy water, and light water moderated, homogeneous and fast breeder experimental reactors.

Following the Conference, an analysis was made by Soviet scientists

of the information described at Geneva and recommendations were made to governmental organizations concerned as to how nuclear reactors might be utilized in the future as a source of electricity. A directive was therefore submitted to the Twentieth Party Congress of the Supreme Soviet in January 1956, proposing the construction of a number of nuclear power plants.

The Twentieth Party Congress thereafter directed the construction of nuclear power plants with a total capacity of 2 to 2.5 million kilowatts of electricity under the Five Year Plan covering the period 1956-60. I. V. Kurchatov, one of the USSR's leading scientists and an enthusiastic supporter of the proposal, pointed out that "although capital investment per unit of rated capacity of atomic power plants is approximately one and one-half times the corresponding capital investment in plants powered by coal, the cost per kilowatt hour of atomic power and coal power plants can be approximately the same." The Five Year Plan proposed construction of "up to ten different types of atomic reactors with a power capacity from 50,000 to 200,000 kilowatts "primarily in areas far away from sources of fuel." Two of the plants were to be built in the Ural mountains area and would have had a total capacity of 1,000,000 kilowatts of electricity. In addition, a 400,000 kilowatts (electric) plant was to be built near Moscow. Kurchatov also indicated that the USSR would collaborate in the field of nuclear energy with other countries "in the socialist camp." The significance of the proposed

Program can be seen, if one keeps in mind its experimental nature, as well as the fact that the British Ten Year program at the time envisaged a total electrical generating capacity of 1.5 to 2 million kilowatts by 1965 and the United States' anticipated total capacity of about 700,000 kilowatts of electricity by 1961.

The Soviet program, announced in 1956 for the development of electric power, was later examined by the Soviet Government. Soviet officials have indicated that as a result of technical difficulties encountered in translating theory into practice, as well as a new analysis of costs per kilowatt hour of electricity from nuclear and conventional plants, this nuclear power program has been rescheduled and stretched out. In order to improve the management of the overall power program, the Ministry of Power Plants was abolished in January 1959 and the program was placed under a newly established Ministry of Power Station Construction. Ignaty T. Novikov was appointed Minister. The proposed power production program was presented to and approved by the Twenty-First Party Congress. The effect of the general cost analysis on the nuclear power program was an extension of the target date for production of the proposed 2 to 2½ million kilowatts of electricity from 1960 to 1965, emphasizing the relatively small part nuclear power is expected to play in the Seven Year Plan for doubling the present rated capacity of power plants to 60 million electrical kilowatts, so as to increase the output of electricity from 264 billion kwh for 1959 to between 500 and 520 billion kwh by 1965.

At the second Geneva Conference on the Peaceful Uses of Atomic

Energy in 1958, Soviet scientists described a very vigorous and large reactor research and development program. In addition to the types of reactors described at Geneva in 1955, Soviet representatives told the conference of a proposed boiling water experimental power reactor to be built at the Ulyanovsk Reactor Center, capable of producing 50,000 kilowatts of electricity. Substantial Soviet progress in most phases of reactor technology was also exhibited. Other significant revelations by Soviet scientists were the announcement of the operation, in September 1958, of the first of six dual-purpose (plutonium and electricity production) reactors capable of producing 100,000 kilowatts of electricity "somewhere in Siberia" and a description of Soviet experimentation in the development of fast breeder reactor technology.

For the purpose of this report, the primary objective of the nuclear power program of the USSR may be considered, as Kurchatov described it in 1956, an "experimental construction program intended to enable selection of the best methods of developing atomic power in the future." Administration of the program concerns several ministries of the Soviet Government, including The Ministry of Medium Machine Building; the Main Administration for Atomic Energy; "Glavatomenergo", one of the Chief Directorates of the Ministry of Power Plant Construction; Ministry of Machine Building and Electrical Equipment; Ministry of Heavy Machine Building; and the Ministry of Instruments and Automation.

The multi-concept Soviet nuclear power development program, which

must include not only reactors being constructed in the USSR but in Soviet-associated countries as well, comprises the following types:

a. Graphite moderated, light water cooled reactor using slightly enriched uranium.

1. Obninsk. The first nuclear reactor to generate electricity in the USSR, the APS-1, was of this type and went into operation in June 1954 at the Obninsk site. Capable of producing 5000 kw of electricity, the reactor has a rated thermal power capacity of 30,000 kw. Research with tubular heat producing elements for the development of superheated steam in this reactor has contributed to the design of larger size reactors at Beloyarsk.

2. Siberian Dual-Purpose Reactor Station. In September 1958 the Soviet Government announced that the first of six 100 megawatt (electric) graphite-moderated, light water-cooled, dual purpose reactors (for plutonium and electricity production) had been put into operation "somewhere in Siberia."

3. Beloyarsk. The Beloyarsk nuclear power station, which is now under construction and the first two reactors of which are expected to go into operation in 1962, is to include four graphite moderated, light water cooled reactors, each capable of producing 100 megawatts of electricity. Two of the reactors are presently under construction and will be followed by the second two reactors when sufficient experience has been obtained from the first two to warrant

construction of the second two. Each of the reactors will produce superheated steam from nuclear heat.

b. Pressurized Water Reactors

1. Voronezh Power Station. Some 25 miles from Voronezh on the Don River, Soviet scientists and engineers are constructing a nuclear power station which will eventually comprise two 210 MW (electric) pressurized water reactors. The one reactor presently under construction is to have uranium oxide fuel elements clad in zirconium. It is expected to be completed in 1961-62.

2. Leningrad Power Station. Two 210 MW electric reactors, similar to the Voronezh reactors, are to be constructed to power a station for the Leningrad District after experience has been gained from the Voronezh plant.

3. Other Pressurized Water Reactor Development. The Soviet Government has also reported undertaking construction at Obninsk of a small pressurized water mobile reactor capable of producing two megawatts of electricity. Although the reactor was scheduled to be put into operation in 1959, there has been no recent information released on the status of the project.

Three pressurized water reactors, each with a thermal output of 90,000 kilowatts, are providing the propulsive power for the Soviet Icebreaker, the Lenin, a 16,000 ton ship of 44,000 shaft horsepower, which began sea-test trials in September 1959.

c. Heavy Water Moderated Reactors

Although the Soviet Government has undertaken a considerable amount of developmental work on lower power heavy water moderated reactors for research purposes, none are being constructed within the USSR for the production of electricity or as power experiments. Soviet scientists and engineers are, however, providing materials, information and other forms of assistance to engineers in Czechoslovakia and East Germany, who are presently constructing heavy water moderated reactors.

In Czechoslovakia a 100 megawatt (electric) reactor, using natural uranium fuel and gas cooling, is in the final stages of construction near Bohunice in Slovakia, while in East Germany a gas cooled reactor, using slightly enriched uranium, of 70 MW (electric) capacity for the first core is also in the late stages of construction at Neuglobsow, north of Berlin. Both reactors are scheduled to go into operation in 1960-1961.

d. Other Reactor Development Experiments

In addition to the large size, advanced-type reactors mentioned above, the Soviet Government has announced interest in or work on the following reactor experimental types requiring further development:

1. Fast Breeder Experiments. Soviet research on fast breeder reactors dates from 1955, when a zero power critical assembly

(BR-1) was put into operation. A 100 watt unit, known as BR-2, was later built and dismantled. BR-5, a 5000 kilowatt (thermal) sodium cooled fast reactor went into operation in the spring of 1958 at Obninsk. The primary purpose of the BR-5 is to perform research and development work with plutonium fuel elements. Results of the BR-5 are expected to assist Soviet scientists and engineers in the design and construction of a larger experimental power reactor, the BN-50.

BN-50, a fast breeder, sodium-cooled experimental reactor, is presently in the design stage for construction at the Ulyanovsk Reactor Center. The reactor is expected to produce 50 electric megawatts and will have fuel elements made of a plutonium-uranium alloy. After operation of the BN-50, construction will begin on a full scale 250 electrical megawatt plant (BN-250) using the same basic principles. It is expected to have a maximum fast neutron flux of $1.3 \times 10^{16} n/cm^2/sec.$ and to have plutonium fuel elements.

2. Other Reactor Concepts. In addition to the BN-50 Fast Reactor, the Soviet Government has indicated their intention to construct the following experimental reactors at the Ulyanovsk Reactor Center: a 50 MW (electric) boiling water reactor using 1.5% enriched uranium oxide fuel elements clad in zirconium alloy, scheduled to begin operation in 1961; and a 35 MW (thermal) homogeneous heavy water reactor which will use a suspension of finely powdered uranium oxide in heavy

water and is presently under construction.

As noted above, many of the principal reactor types employed in other advanced countries are being studied in the USSR, but others have received little or no attention, at least until U.S. interest was revealed at the Second Geneva Conference. These include organic cooled or moderated, pressurized heavy water, water moderated superheat, graphite moderated, gas cooled, graphite clad fuel-gas cooled, beryllium oxide moderated gas cooled reactors.

Power Reactor Development Projects in the USSR

Designation	Location	Type	Electric Power(MWe)	Fuel	Completion Date
		In Operation			
1. APS-1	Obninsk	Graphite	5	5% U-235	1954
2. Siberian[a] Station (Reactor #1)	Unannounced	Dual Purpose Graphite	100	Natural U	1958
		Under Construction			
3.	Obninsk	Mobile PWR	2		1958[b]
4. Voronezh[c] Station	New Voronezh	PWR	210 each	1.5% U-235 in UO_2; Zr clad	First reactor 1962
5. Byeloyarsk[d] Station	Near Byeloyarsk	Graphite	100 each	1.3% U-235 in 9% Nb alloy	First 2 reactors 1961-2
		Planned			
6.	Ulyanovsk	BWR	50	1.5% U-235 oxide elements clad in Zr alloy	Unannounced
7.	Ulyanovsk	Homogeneous D_2O Breeder	35 MW(th)	Powdered UO_2 in D_2O	Unannounced
8. Siberian Station Reactors #2 to 6	Unannounced	Dual Purpose Graphite	400 MWe	Natural U	Unannounced
9. Leningrad Station	Near Leningrad	PWR	210	1.5% U-235 in UO_2;Zr clad (Similar to Voronezh Station)	Unannounced
10. BN-50	Ulyanovsk	Fast Breeder	50	Pu-U alloy	Unannounced

Designation	Location	Type	Electric Power(MWe)	Fuel	Completion Date
11. BN-250	Unannounced	Fast breeder; sodium cooled	250	Pu	Unannounced

Notes

(a) One of six reactors for production of plutonium and power.

(b) Scheduled to be completed in 1958; thought to be in operation now, although operation not confirmed by Soviet Government because of military application of reactor.

(c) One of two similar reactors; total capacity 420 MWe; first to be completed in 1961; second to be built after sufficient experience gained from first.

(d) One of four similar reactors; total capacity 400 MWe; first two reactors scheduled for completion in 1961; second two reactors to be built after first two reactors are in operation.

(3) Controlled Thermonuclear Research. The importance assigned by the USSR to the problem of attempting to produce power from nuclear fusion reactions* is amply attested in statements made by Premier Khrushchev and Academicians Nesmeyanov and Lavrentiev during the Twenty-First Congress of the Communist Party, November 1958. Among the reasons why the development of a nuclear fusion (controlled thermonuclear) reactor is important are the virtually inexhaustible source of

* Nuclear fusion reactions are processes in which two very light nuclei react to form a heavier product nucleus, with the release of energy. Example: $D + T \rightarrow He^4 + n + 17.6$ Mev.

cheap fuel, non-radioactive reaction products, inherent safety, the possibility of somewhat greater efficiency in the conversion to electrical energy, and possible advantages for use for space propulsion purposes.

First public revelation of Soviet activity in this field came on April 26, 1956, when I. V. Kurchatov presented a paper on controlled fusion research in the USSR during a visit to the British nuclear research center at Harwell. Research based on the use of a high-current discharge in a linear device was revealed at that time. Subsequent presentations by Soviet scientists, particularly at the Second Geneva Conference, have revealed a program of considerable scope, nearly as large and diversified as the U.S. program.

Although Soviet scientists are carrying out research on a scale almost as large as that in the United States, involving several institutes, Soviet scientists appear to be no nearer the development of a controlled fusion reactor than scientists in other countries. It is possible that, as in other leading scientific nations, the USSR may develop within the next couple of decades a fusion device capable of producing more energy from controlled thermonuclear reactions than the machine consumes. However, it would probably be many additional years before it could be determined whether a fusion reactor capable of producing economically competitive power could be achieved.

The USSR program very roughly parallels the U.S. program (or U.S. and U.K. programs) as regards work on particle and plasma injection and

trapping, stability theory, pinch discharges, ion cyclotron heating processes, diagnostic techniques, rotating plasmas, and plasma oscillations. The USSR is not known to have comparable efforts on magnetic compression (both "slow" and "rapid"), confinement and heating by relativistic electrons (Astron), stellarator confinement achieved by strong external fields, or "hard-core" pinches. Among the notable Russian activities are:

(a) OGRA. A large fraction of the Soviet effort is centered around the use of a very large ion injection and magnetic trapping device, "OGRA", at the IAE in Moscow. In concept it is somewhat similar to the DCX machine at Oak Ridge.

OGRA is a large magnetic mirror machine, consisting of a stainless steel tube, about 12 meters long and 1.4 meters in diameter. Mirror coils produce a magnetic field of 8000 gauss near the ends, and additional coils produce a field of 5000 gauss in the intermediate region. Molecular (D_2^+) ions, accelerated to 200 kev, are injected transversely at the median plane, broken up on the residual gas or incipient plasma, and trapped. The device was completed in the fall of 1958 and has been undergoing preliminary experimentation, with only moderate success.

(b) Other Trapping and Heating Experiments. Small magnetic trap experiments have been performed to test injection techniques and single-particle confinement properties.

Experiments have also been conducted in Soviet labora-

tories in which radio-frequency fields have been used to enhance magnetic mirror fields for confinement purposes.

A variety of experiments on r-f heating have been performed, including considerable work on ion cyclotron resonance heating.

At the Uppsala Conference in 1959 Soviet scientists described further experiments on plasma confinement in an ion magnetron, a rotating plasma device.

(c) Pinch Experiments. In Leningrad the USSR has a large slow toroidal pinch machine Alpha, modelled after the UK's Zeta. The results obtained are generally similar to Harwell's.

Soviet scientists have done considerable work on fast pinch discharges, both the "dynamic" and "stabilized" types, and have observed so-called "instability neutrons", as have the U.S. and U.K. There is allegedly little optimism about the long-range prospects for such devices.

Two large toroidal devices at Moscow yield results which can be compared to those obtained in the United States with stellarators. However, in these Russian devices, the confinement is provided solely by the discharge current and a simple axial field, rather than by the refined magnetic fields used in our stellarators. A third toroidal device is being constructed, which will feature a relatively fast rise in the external magnetic field -- 4×10^{-5} sec. for one quarter cycle.

At the Second Geneva Conference in 1958, the Soviet physicist, L. A. Artsimovich, indicated that inasmuch as none of the various approaches to controlled fusion appears decisively superior, investigations in the near future should be carried out in diverse directions.

(4) High Energy Physics. One of the important areas of nuclear research being explored by Soviet scientists is the study of atomic particles (protons, neutrons, and electrons) and their collisions at high energies from which emerge new elementary particles -- mesons, hyperons, anti-protons, etc. Although research is being carried out actively in lower energy ranges, Soviet scientists are expending a great effort in the study of elementary particles traveling at higher energies, i.e., above 200 million electron volts (200 Mev). This study, which includes the experimental techniques for acceleration, production and detection of the elementary particles, is called "high energy physics." At the present time, high energy physics does not have any military or other known practical application, and is therefore not classified.

Significant governmental support for nuclear research in the USSR began in the 1930's not long after the development of the concept of the cyclotron and the fission of the atom by artificial means. During the early 1930's accelerating machines were built at two of the leading research institutes -- a 0.5 Mev Cockroft-Walton generator for the Physico-Technical Institute in Leningrad, and a Van de Graaff

generator for the Physico-Technical Institute at Kharkov. The first cyclotron in Europe, a 4 Mev machine, was built under the supervision of I. V. Kurchatov and installed at the Radium Institute in Leningrad, where it was put into operation on a limited basis in 1937. During World War II it was dismantled and moved to the East to prevent its falling into the hands of the invading German Army.

After World War II and scientists had returned from defense work, there was a renewed interest in nuclear physics research using accelerators. In 1949 a 680 Mev synchrocyclotron was completed at a laboratory which is now part of the Joint Institute of Nuclear Research at Dubna. The machine used the phase stability principle developed independently by V. I. Veksler and E. M. McMillan. Publication of data in 1954 obtained through the use of this apparatus did much to stimulate interest in the use of large machines in high energy physics research work. This was followed by construction of high energy machines at Moscow, Kharkov and Leningrad.

By the beginning of 1960 the highest energy accelerator in operation in the Soviet Union was the 10 Bev synchrophasotron which was also constructed at Dubna, one of the important locations for work in high energy physics, employing several hundred technicians and at least one hundred scientists. In addition to the 680 Mev and 10 Bev machines mentioned above, there is also a 120 Mev heavy ion cyclotron for research in lower energy physics. By the terms of an agreement signed with other

Soviet Bloc countries* in March 1953, the center is supposed to be under an international direction. However, the director and heads of all laboratories are reportedly Russians. The work reported by Dubna scientists has in general been very good.

Other laboratories engaged in high energy physics research are scattered throughout the country, including the Institute for Atomic Energy, the Lebedev Physical Institute, the Institute of Theoretical and Experimental Physics, the Institute of Physical Problems, Moscow State University, Ukrainian Physical Technical Institute at Kharkov, and the Kiev Physics Institute.

International high energy physics conferences, which have been attended by Soviet and American scientists, revealed the general high calibre of work in this field by Soviet scientists and the development of a healthy respect for their work by American counterparts. As in other fields of science, the calibre of research tends to vary according to the degree of concentration upon it. High energy physics has been one of the areas in which Soviet scientists have put forth a major effort. The consensus of American scientists competent in this field is that except for rare cases Soviet scientists are still lagging behind their American counterparts, despite good work

* Members of the Joint Institute of Nuclear Research are: Albania, Bulgaria, Communist China, Czechoslovakia, East Germany, Hungary, North Korea, Mongolia, Poland, Rumania, North Viet-Nam, and the USSR.

noted above.

Soviet High Energy Accelerators

	Institution	Location	Type	Energy Level	Completion Date
1.	Joint Institute of Nuclear Research	Dubna	F.M. Cyclotron	680 Mev	1949/1953
2.	Lebedev Institute	Moscow	Electron Synchrotron	280 Mev	1950
3.	Ukrainian Technical Institute	Kharkov	Electron Linear Accelerator	1 Bev	Design and Model Studies 1956
4.	Lebedev Institute	Moscow	Electron Synchrotron	600 Mev	Construction Started 1956
5.	Atomic Energy Institute	Moscow	Electron Synchrotron	1 Bev	Model Tests 1957
6.	Physical Institute	Moscow	Electron Synchrotron	4-6 Bev	In Design Stage
7.	Joint Institute of Nuclear Research	Dubna	Proton Synchrotron	10 Bev	1957
8.	Research Institute for Electro-Physical Instruments	Leningrad	Proton Synchrotron	200 (650) Mev	1958*
9.	Thermotechnical Institute	Moscow	Proton Synchrotron	7 Bev	1959**
10.	Research Institute for Electro-Physical Instruments	Leningrad	Proton Synchrotron	50 Bev	In planning stage

* Model for 7 Bev Machine.

** Model for 50 Bev Machine.

d. Nuclear Propulsion

Following the First United Nations Conference on Atomic Energy at Geneva in August 1955, where a substantial amount of Soviet technology was disclosed, the Soviet Government began to propagandize the benefits of the peaceful uses of the atom in nuclear propulsion. Transportation vehicles mentioned by Soviet representatives as being planned in the future were a nuclear propelled icebreaker, merchant ship, locomotive and even an automobile.

The first nuclear propelled vessel to be put into operation in the USSR using nuclear energy has been the icebreaker "Lenin" which went into operation in September 1959. Use of such a ship is especially important to the development of the Soviet Arctic because of the necessity of operating under icebround conditions. Increasingly more attention is being paid to the frozen north by the Soviet Government because of the military bases in that area, as well as the important meteorological studies being undertaken as part of a weather control system. Normal commerce comes almost to a standstill in the Soviet Arctic most of the months of the year. A nuclear propelled icebreaker could operate with an almost unlimited range.

The 16,000 ton "Lenin" generates 44,000 horsepower from her main engines and is capable of a speed of 18 knots in clear water. Three pressurized water reactors, each capable of producing 90,000

thermal kilowatts, provide power to the four turbogenerators. Any two of the reactors can propel the ship. The reactor uses 85 kilograms of uranium-235 in oxide form enriched up to five percent.

In view of the importance of such vessels to the development of the Soviet Arctic, the construction of additional icebreakers may be expected in the relatively near future.

The experience gained from the operation of the "Lenin" during the coming year may provide a great deal of reactor technology usable in the propulsion of ships of the Soviet Merchant Marine, such as the nuclear propelled whaler now reportedly being designed, tankers, or other types of cargo vessels.

It is also known that the Soviet Union has been interested in the development of a nuclear powered aircraft and submarines.

e. The Radioisotopes Program

It has been noted previously in this report that radioactive isotopes had been utilized in the Soviet Union long before World War II. In the early period radioisotope production was accomplished in small amounts using laboratory neutron sources and accelerators. The limitation of radioisotope quantities therefore restricted their use in the national economy. However, construction of the first cyclotron in the USSR brought with it the production of greater quantities of radioisotopes, which would expand their uses throughout the country. With the construction of nuclear reactors and additional cyclotrons in the late forties, still greater quantities of

radioactive and stable isotopes became available for widespread use in all phases of the economy.

(1) Organization of Program. Although there are many governmental organizations involved in the isotope program as a whole, i.e. the production, distribution and utilization of isotopes, there are two principal organizations primarily concerned with the administration of the program. An office of the Main Administration for the Use of Atomic Energy (GLAVATOM), known as the Administration of Production and Utilization of Radioactive Isotopes, provides technical information regarding the production, application and measurement of radioactive isotopes. Actual distribution of radioactive isotopes is administered by the Department of Isotopes of the State Union Trust "Soyuzreaktiv" of the Ministry of Chemical Industry under regular commercial agreements with the purchaser.

In order to facilitate the promotion and distribution of isotopes in the USSR, the "Soyuzreaktiv" has opened a large "demonstration store" called "The Isotope" on Lenin Prospect in Moscow. The store, in effect, is to serve as a permanent exhibit of equipment for isotope users, and an order house for purchases of isotope sources and equipment by representatives of enterprises, institutes and hospitals. Topical exhibits will be held from time to time on the various uses of isotopes and nuclear emissions in various fields.

With the partial decentralization of responsibility in economic planning and direction, in 1957 there was initiated in the

interest of greater efficiency a trend in giving the Union republics more responsibility in administering their own economic affairs. Scientific research centers, established in or near the capitals of certain Union republics in order to assist the development of the local economy, are to be provided with equipment capable of producing radioisotopes. This means that instead of having to rely on isotopes produced in European Russia and transported over thousands of miles, the Union Republics will soon have sufficient isotopes produced in their own region capable of taking care of most of their needs. It is not known at this time what mechanics will be developed for the administration of the isotope programs of the individual republics, although this will in all probability be under the overall direction of the regional economic councils.

In addition to the organizations with geographic responsibility over isotope programs, certain ministries have a functional responsibility for the use of radioisotopes in their respective industries.

Through this seemingly intricate system of programmatic direction, the radioisotope program of the USSR, which is considered second only to that of the United States in size and effort, is playing an increasingly important role in the national economy of the USSR and may be expected to expand in the future.

(2) Production. Most of the isotopes produced for the national economy today are produced in nuclear reactors and accelerators.

The nuclear reactors utilized for radioisotope production are of three types -- graphite, heavy water and light water moderated. Fluxes of the reactors are usually 10^{12} and 10^{13} neutrons per cm per second, although fluxes of higher densities are available as required. The location of all reactors used in the Soviet isotope program has never been made public, possibly because of their location at the production sites for fissionable materials. In addition to the "production sites" it is known that isotopes have been produced at various institutes around Moscow, such as the Institute for Atomic Energy.

Fission product separation also provides a source for isotopes. Among the more important isotopes recovered from fission products are iodine-131, krypton-85, cesium-137, strontium-90, promethium-147, technetium-99, europium-155 and ruthenium-106. As of 1957 Soviet scientists had separated fourteen different isotopes from fission waste. A fission production separations plant was scheduled to go into operation in 1959. Stable isotopes are produced by the physico-chemical methods mentioned above and include boron-10, nitrogen-15, carbon-13, neon-22, oxygen-18 and krypton-86. A limited amount of isotopes, such as sodium-22, vanadium-48, manganese-52 and arsenic-74 are still being produced with accelerators.

At the Geneva Conference of 1958, A. V. Topchiev, a ranking official of the Soviet Academy of Sciences, reported that the USSR is producing more than 90 radioactive isotopes, 170 stable isotopes, more

than 360 labelled compounds, and more than 100 types of such important isotopes as cobalt-60, cesium-137, strontium-90, promethium-147, and many others. Topchiev further reported that the Soviet Government expected to produce the following in 1958:*

190,000	curies	of	Co-60
1,500	"	"	Cs-137
1,200	"	"	I-131
1,100	"	"	P-32
1,000	"	"	Au-198
900	"	"	S-35
800	"	"	Ir-192
750	"	"	Tm-170
200	"	"	C-14

In terms of shipments, the USSR has increased production from 11,500 shipments in 1954 to 26,000 in 1957. The total radium gram equivalent of quantities has been increased from 2,000 in 1955 to more than 90,000 in 1957. In 1955 there were only 55 types of isotopes available with more than 90 available in 1957. A review of such figures reveals the great emphasis being placed upon isotope production for not only the use of the Soviet economy, but for shipment abroad as well.

For a number of years the Soviet Union has been shipping isotopes to countries of the Soviet Bloc. In 1957, some 3000 shipments were made abroad, primarily to Bloc countries. Since then the USSR has reportedly started increasing its shipment of isotopes to non-Bloc countries. To handle such demand, an export department has been

* The most recent information published by the Soviet Government on isotope production in the USSR.

established in the Soyuzreaktiv.

Use of this large production is dispersed throughout all phases of the economy. Several thousand industrial plants use radioisotopes for gamma radiography, thickness gaging, density gages, liquid level gages, and other known uses. Similarly broad utilization may be found in various fields of research, diagnosis and therapy in medicine. Isotopes are also used to improve agricultural techniques and production.

A Soviet estimate lists a total savings of 1.5 billion rubles per year* with the following breakdown:

a. Mining and Oil: 600 million rubles
b. Gamma Radiography: 300 " "
c. Gaging: 250 " "
d. Metallurgy: 100 " "

In view of the Soviet objective to expand the utilization of isotopes as much as feasible in all phases of the economy, as directed by the Seven Year Plan, the total savings to the economy may be expected to increase sharply through the end of the present economic plan in 1965.

3. International Cooperation

Although the Soviet Union was quite reluctant at first to accept the December 8, 1953, proposal of President Eisenhower that it participate

* Official rate of ruble is 4 to $1.00.

in an international agency concerned with the development of the peaceful uses of atomic energy, the Soviet Government did begin in January 1955, however, to evince an interest in international cooperation in this field.

Soviet representatives began participating actively at that time in the U.N. Advisory Committee, which was undertaking preparations for the First U.N. sponsored conference on the Peaceful Uses, subsequently held at Geneva in 1955. The Soviet Government also began negotiations in the Spring of 1955 on a series of agreements for cooperation with other countries, which provided for assistance in the establishment of nuclear research and later nuclear power programs. In March 1956 the Soviet Government established the Joint Institute of Nuclear Research at Dubna, near Moscow, a cooperative institute comprising members of the Soviet Bloc.

Following active participation by a large delegation at the First U.N. Conference at Geneva, Soviet scientists and technicians continued to give papers and take part in most large scientific conferences and meetings. In September 1958, Soviet delegates to the Second U.N. Atomic Energy Conference again gave a creditable account of the advanced stages of their programs. The USSR has also participated in the International Atomic Energy Agency.

In the Fall of 1959, the Soviet Government expanded its program of bilateral relationships to leading Western countries with the negotiation of a reciprocal exchange arrangement with the United States

(in November 1959) and with France (April 1960). These activities are more fully described in the following paragraphs.

a. Soviet-Bloc Cooperation

In view of the announced U.S. intention in September 1954 to negotiate agreements for cooperation with friendly nations, the shipments of uranium from Bloc countries to the USSR, and the special relationship existing between the Government of USSR and other communist governments, it was only natural that the Soviet Government should accede to their needs and initiate a program, in the spring and summer of 1955, of international cooperation in the peaceful uses of atomic energy with the Soviet Bloc.

(1) Research Agreements. On January 17, 1955, the Soviet Government indicated that it would provide material, equipment and data for "raw materials" to Communist China, Poland, Czechoslovakia and East Germany. This was followed on April 5, 1955, by a Soviet decision to supply reactors to other Soviet Bloc nations.

During the Spring of 1955, Agreements for Cooperation were concluded by the Government of the USSR with the governments of the Chinese Peoples Republic, Hungarian Peoples Republic, the German Democratic Republic, the Polish Peoples Republic, the Czechoslovak Democratic Republic, the Rumanian Peoples Republic, and the Bulgarian Peoples Republic. These were followed in 1956 by the conclusion of bilateral agreements with the Yugoslavian Peoples Republic and the Egyptian Republic, and later still with the governments of North Korea and Iraq.

In general, the bilateral agreements provide for scientific

and technical assistance by the Soviet Union to cooperating countries in the establishment of nuclear research programs. This was apparently in partial recognition of the uranium resources made available to the Soviet Government as part of the war reparations payments.

Under the terms of the 1955 agreements, the Soviet Government agreed to help install in cooperating countries an experimental nuclear reactor and a cyclotron; provide the necessary scientific and technical data related thereto; and train the necessary scientists. The agreement with the Government of Yugoslavia provides for aid in construction of a research reactor, but no cyclotron, while the Egyptian agreement provides for assistance in building "scientific facilities" which includes research reactors and electrostatic generators.

Three types of research reactors were selected to be built in cooperating countries:

(a) TVR-S Reactor. This is a heavy water moderated and cooled research reactor which utilizes graphite as a reflector and 2% Uranium-235 as fuel. Capable of producing thermal power of 7000 to 10,000 kilowatts, the reactor has a maximum neutron flux of 5.5×10^{13} n/cm^2/sec. It was designed for research purposes and for radioisotope production.

Reactors of this type have been constructed and are now operable at the Institute of Atomic Energy at Peking, China, and at the Boris Kidric Institute near Belgrade, Yugoslavia.

(b) WWR-S Reactor. Light water provides the moderator, coolant and reflector for the WWR-S swimming pool-type research reactor, which has a thermal power rating of 2000 kilowatts and a maximum flux of 2 x 10^{13}n/cm^2/sec. Using uranium enriched up to 10% U-235, the reactor is especially designed for physical and biological research and isotope production.

This type of reactor has been constructed at the Institute of Nuclear Physics in Husinez-Rez, Czechoslovakia; the Central Institute for Nuclear Physics near Dresden, in East Germany; the Nuclear Research Center, Swierk, Poland; the Central Institute of Physical Research, near Budapest, Hungary; and the Nuclear Physics Institute, Bucharest, Rumania. Each of these reactors is now operable.

(c) IRT-1000 Reactor. A second pool-type reactor, using light water as a moderator, coolant and reflector, has also been made available for export to cooperating countries. Designated IRT-1000, the reactor uses 10% enrichment in U-235; has a thermal power rating of 1000 to 1700 kw; and a maximum neutron flux rating of 1.2 x 10^{13}n/cm^2/sec.

Under the provisions of the bilateral agreement, such a reactor is under construction at the national research center near Sofia, Bulgaria. The Soviet Government is also providing the fissionable and other materials for the reactor.

As provided in the agreements concerned, the Soviet Government has transferred to cooperating countries cyclotrons, with a pole tip

diameter of 120 cm and capable of producing 25 MEV alpha particles to the Chinese Peoples Republic, the Czechoslovak Republic, the German Democratic Republic, the Polish Peoples Republic and the Rumanian Peoples Republic. A 48 MEV alpha particle cyclotron having an electromagnet with a 150 cm polar tip diameter has also been constructed for the Chinese Peoples Republic. The latter has also received from the USSR a 2.5 Mev electrostatic generator similar to that delivered to the United Arab Republic.

In addition to the above, the USSR has provided to cooperating countries "hot" cells, manipulators, electronic apparatus,' and dosimetric equipment for hot laboratories.

Overall costs of the designs, equipment and materials is borne by the cooperating country and is determined by the parties to the agreement. Information and documentation are provided free of charge, except for the actual expenses related to preparation of technical documents. Soviet specialists have been sent to cooperating countries to assist in construction and operation of equipment. Specialists from cooperating countries have received "on-the-job" training in the USSR. Costs of materials, equipment and other assistance received could be paid for with commodities from the cooperating countries.

(2) "Power" Agreements. The Soviet Union is also providing scientific and technical aid for nuclear power development to certain countries under bilateral agreements. In addition to providing assistance to these countries in developing much needed electrical

generating capacity, the Soviet Union hopes to obtain construction and operating experience as part of its national plans to develop economic nuclear power.

As a result of an agreement for cooperation with the USSR, apparently concluded in January 1957, the Government of the Czechoslovak Republic is constructing with Soviet assistance a heavy water moderated, gas cooled reactor at Bohunice in Slovakia, with a planned capacity of 150 Electrical Megawatts, but reportedly now designed for 100 electrical megawatts. Carbon dioxide gas under a pressure of 60 atmospheres is to be utilized to remove the heat. Natural uranium from Czechoslovakia will be utilized as fuel.

Design of the reactor and fuel elements is based on research carried out previously in the USSR, the results of which have been provided to Czechoslovak scientists and engineers. The idea of first constructing a pilot plant was discarded because of the expenditures and time involved. Soviet specialists have assisted with the planning and construction of the reactor. Construction of the plant, as well as manufacture of the equipment, will be done by Czechoslovak industry. The reactor, originally scheduled to be completed in 1960, will probably not be in operation before 1965.

In July 1956 an agreement was reached between representatives of the governments of the USSR and the German Democratic Republic whereby the Soviet Union would provide assistance with the construction of a pressurized water reactor to be constructed at Neuglobsow, 45 miles north of Berlin. The reactor, which will be fueled with natural and enriched uranium, is being constructed largely by Soviet scientists and

engineers. Designed in two phases, the first stage is expected to produce a maximum of 250 megawatts of heat and 70 megawatts of electricity, going into operation in 1961. The capacity of the Phase II reactor is expected to be 150 electrical megawatts.

Although no agreement for cooperation has been signed to provide nuclear power assistance, governmental representatives of the Peoples Republics of Hungary and Poland have indicated an interest in the construction of nuclear power plants in the future.

An agreement to provide scientific and technical assistance in connection with the construction of a nuclear power reactor was reportedly discussed by representatives of the governments of India and the USSR in March 1960.

In addition to the above forms of assistance, the Soviet Government has provided to cooperating countries radioactive isotopes, radioactive tracer compounds and cobalt sources, as well as research quantities of uranium-233, plutonium and tritium.

(3) The Joint Institute for Nuclear Research, Dubna.

Upon the initiative of the Soviet Government, an agreement establishing the Joint Institute for Nuclear Research was signed on March 26, 1956 by governmental representatives of the USSR and ten Soviet Bloc nations. The Joint Institute was to include two existing research laboratories, the Electro-physical Laboratory and the Institute of Nuclear Problems, and to be under direction of Dmitri I. Blokhintsev, famous for his role in the design, construction and operation of the first atomic power

plant in the Soviet Union. Vice-directors were to be from Soviet Bloc countries. Subsequently, the town of Dubna was developed near the location of the Institute, sixty-odd miles from Moscow on the Volga River.

Some of the leading scientists of the USSR were assigned to the Institute, viz., V. I. Veksler, director of the Laboratory of High Energy Physics; N. N. Bogolyubov, director of the Laboratory of Theoretical Physics; I. M. Frank, director of the Laboratory of Neutron Physics; V. P. Dzhelepov, director of the Laboratory of Nuclear Problems; and in 1957 Georgi Flerov, director of the Nuclear Reactions Laboratory. Thus, the directors of the five laboratories were to be from the USSR.

Two large Soviet accelerators of important significance to high energy physics work, in which field the Institute was to concentrate, were provided to the Institute as part of the USSR's financial contribution to the international arrangement -- a 680 Mev proton synchrocyclotron and a 10 Bev proton synchrotron.

Since its inception, the Joint Institute has not only become a center for nuclear research but also a training center for scientists and technicians of the Soviet Bloc.

b. Non-Bloc Relationships

Subsequent to the conclusion of bilateral agreements with Soviet Bloc nations in the Spring of 1955, and the First Geneva Atomic Energy Conference in August of the same year, Soviet governmental

representatives began making offers of atomic energy assistance to selected non-Bloc countries.

In response to such an offer, agreements for cooperation, providing for assistance with nuclear research programs generally similar to those concluded with Soviet Bloc countries, were concluded with the Governments of Yugoslavia (January 28, 1956), Egypt (July 12, 1956), and Iraq (August 17, 1959).

In addition to offers to provide for the establishment of nuclear research programs, the Soviet Union has reportedly offered to cooperate with other countries outside of the Soviet Bloc in the development of nuclear power programs.

A memorandum providing for a reciprocal exchange of visits and information in the peaceful uses of atomic energy was signed by representatives of the Soviet and U.S. Governments in November 1959. The reciprocal exchange, which is expected to be of benefit to the International Atomic Energy Agency, provides for exchanges in the field of power reactors, controlled thermonuclear reactions, high energy physics and neutron physics. A more complete discussion of this subject is provided for in a later section of this report.

In March 1960 a team of Soviet specialists visited India and reportedly held discussions with the Indian Government on an agreement for cooperation which would provide for the construction of a nuclear power reactor in that country. The Soviet Government has also held discussions with the Government of Indonesia on atomic

assistance, although no agreement has reportedly yet been reached.

During a recent visit by Premier Khrushchev to France, V. S. Emelyanov of the Soviet Main Administration for Atomic Energy and Pierre Couture of the French Commissariat for Atomic Energy, signed an agreement for cooperation in Paris on April 1, 1960, which provides for an exchange of visits and information by scientists and engineers of the two countries.

c. International Atomic Energy Agency Participation

On September 20, 1956, the Soviet Government was one of the 81 governments which signed the Statute establishing the International Atomic Energy Agency. The Soviet parliament ratified the Statute on April 8, 1957. As provided by the Statute, the Soviet Government has been represented on the Board of Governors since its inception. Soviet nationals have also been employed in various capacities in the permanent IAEA organization in Vienna.

Soviet Government participation in the IAEA has included offers of 50 kilograms of contained uranium-235 enriched up to 20 percent, the cost-free services of 20 to 30 consultants, a number of nuclear science fellowships, voluntary contributions to the Special Budget for technical assistance, in addition to the regular percentage contribution to the annual operating budget, and active participation in IAEA sponsored conferences and symposia.

On May 11, 1959, the Soviet Government formalized its offer of uranium-235 to the IAEA by the signature of an Agreement of

Cooperation with the Agency.

It is also expected that the results of the reciprocal exchange arrangements, as provided for in the U.S.-USSR Memorandum of Cooperation dated November 24, 1959, will be of benefit to the IAEA, which is expected to play an important role in the anticipated exchange activities.

d. The Reciprocal Exchange Arrangement with the United States

The policy of the United States relating to exchanges with the Soviet Bloc on which the atomic energy exchange program is based, can be traced to the Heads of Government meeting held in Geneva, Switzerland, in July 1955.

The objectives of this policy, relating to the lessening of world fears and tensions, were intended to be:

(a) "To lower the barriers which now impede the interchange of information and ideas between our peoples.

(b) "To lower the barriers which now impede the opportunities of people to travel anywhere in the world for peaceful, friendly purposes, so that all will have a chance to know each other face to face.

(c) "To create conditions which will encourage nations to increase the exchange of peaceful goods throughout the world."

On the "potentials of atomic science" it was noted that it "possesses a tremendous potential for helping raise the standards of living and providing greater opportunity for all the world."

The manner of implementing this policy, which would bring

about a progressive elimination of barriers "as are to the mutual advantage of the countries and peoples concerned", was left to the Foreign Ministers and their staffs in meetings which began in October 1955. During this and subsequent meetings extending over a two year period, the United States proposed a general visit exchange program based on reciprocity, but could not obtain the approval for such a program from the Soviet Union.

The policy of the U.S. Government to encourage mutually beneficial contacts with certain Eastern European countries was expressed in a statement by the President on June 29, 1956, re-affirming the seventeen point program advanced by the Western Foreign Ministers at Geneva in October 1955.

From October 28, 1957 to January 27, 1958, final negotiations on a formal exchange were conducted in Washington between representatives of the governments of the United States under the direction of Ambassador William S. B. Lacy, and the Union of Soviet Socialist Republics, under the direction of Ambassador G. N. Zaroubin. The result of these negotiations was the development of an agreement on exchanges in the cultural, technical and educational fields. Specific stated objectives of the agreement were the improvement of mutual understanding between the peoples of the two countries, the betterment of relations between the two countries, and a lessening of international tensions.

Although the proposed exchange projects in the scientific

and technical fields for the calendar years 1958 and 1959 covered by the Lacy-Zaroubin Agreement did not directly include the specific interests of the U.S. atomic energy program, employees of the U.S. Atomic Energy Commission and its contractors did participate in many of the conference and visit exchange projects, due to the broad application of atomic energy in many fields of research and scientific disciplines training. Section XIII of the Agreement, however, did provide for an exchange of exhibits in the peaceful uses of atomic energy. The Soviet atomic energy exhibit was displayed as part of the Soviet national exhibition in New York from June 29 to August 19, 1959, and the U.S. atomic energy exhibit was displayed as part of the United States national exhibition in Moscow from July 25 to September 5, 1959.

In April 1959 the Atomic Energy Commission discussed a proposal concerning the possibility of arranging for the exchange of visits of U.S. and USSR scientists in the field of thermonuclear research in such a way that the International Atomic Energy Agency and its member states would benefit from the program, as proposed by Chairman McCone in his September 1958 speech before the Third General Conference of the IAEA.* Inasmuch as the Scientific Advisory Committee

* In an address to the 3rd General Conference of the International Atomic Energy Agency in September 1958, Mr. McCone said:
"More specifically, in the field of controlled thermonuclear fusion, the United States proposes that the Agency undertake to serve as the medium through which its members engaged in controlled fusion research freely exchange technical information. This is, of course, an extension of the constructive cooperation which prevailed at the meeting earlier this month in Geneva. I can assure you of the full cooperation of my Government."

of the IAEA was scheduled to meet in Vienna in May, Dr. I. I. Rabi, U.S. representative to the Committee, and Dr. John A. Hall, AEC Assistant General Manager for International Activities, were requested to discuss in a preliminary manner with V. S. Emelyanov, Soviet representative to the Committee and Director of their Main Administration for the Utilization of Atomic Energy, the possibility of an exchange on controlled fusion and nuclear power. Professor Emelyanov reacted favorably to the proposal and agreed to discuss the program with his Government upon his return to Moscow.

Soviet Vice Chairman Kozlov and U.S. Vice President Nixon exchanged visits to various cities and sites, including atomic energy facilities, in 1959. Mr. Kozlov visited the Berkeley Laboratory, the Shippingport power station, and the Savannah merchant ship facility at Camden, New Jersey, during his visit to the United States in July. Vice-President Nixon, accompanied by Admiral Rickover, visited the nuclear power station of BELOYARSK and the icebreaker "LENIN" during their visit to the USSR in August.

At the invitation of the United States Government, Premier Khrushchev visited the United States in September 1959, and Professor Emelyanov accompanied him for the purpose of discussing cooperation in the peaceful uses of atomic energy.

On September 16, 1959, Emelyanov discussed with AEC Chairman John A. McCone, the subject of an exchange in the peaceful uses of

atomic energy and the sharing of information on a world wide scale through the International Atomic Energy Agency.

The areas of exchange specifically discussed included research and power reactors technology, basic research in the physical and life sciences, including the field of high energy physics, as well as controlled thermonuclear reaction technology.

On September 24, Professor Emelyanov and Chairman McCone continued discussions on atomic energy exchanges between the two countries.* These talks proved to be very useful as a preliminary examination of means of cooperation in developing increased knowledge of peaceful atomic energy application. Both principals affirmed their belief that such cooperation should be under the aegis of the IAEA.

Agreements for an initial exchange of visits of atomic scientists to the USSR and the U.S. by Chairman McCone and Professor Emelyanov, developed at this meeting, were later approved by the Heads of Governments of the two countries.

Mr. McCone visited the USSR from October 8 - 18, 1959, with Mrs. McCone; Dr. John H. Williams, an AEC Commissioner; Dr. Frank K. Pittman, Director of the Division of Reactor Development; Dr. Kenneth Pitzer, a member of the General Advisory Committee and Dean of the College of Chemistry of the University of California; Dr. Lyman Spitzer, Director of Thermonuclear Research at the University of Princeton; and Dr. Alvin Weinberg, Director of the Oak Ridge National Laboratory.

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* See AEC Press Releases on the Emelyanov-McCone discussion, which are attached.

During the visit the AEC group visited institutes in Leningrad and Moscow, including the Atomic Energy Institute at Moscow, the ice-breaker "LENIN", BELOYARSK and VORENEZH. In addition, Chairman McCone visited a Ukrainian mining site and mill.

At the end of October 1959, Professor Emelyanov and a party of eight persons visited the United States in reciprocity for the visit of Chairman McCone's group to the USSR.

The main "Agreement between the United States and the USSR for Cooperation in Exchanges in the Scientific, Technical, and Cultural Fields in 1960 - 1961", which was an extension of the Lacy-Zaroubin Agreement, was signed in Moscow on November 21, 1959. Section II of the Agreement, entitled "Scientific Exchanges", provided for cooperation in the field of utilization of atomic energy for peaceful purposes and recognized that specific proposals to this end would be developed by the U.S. Atomic Energy Commission and the Main Administration for the Utilization of Atomic Energy.

On November 24 an addendum to the 1960-61 Lacy-Zaroubin Agreement, covering cooperation between the United States of America and the Union of the Soviet Socialist Republics in the Field of Utilization of Atomic Energy for Peaceful Purposes was signed by Chairman McCone and Professor Emelyanov on behalf of their Governments.

The addendum provides for initial exchanges of visits by scientific and technical personnel specialized in the field of

thermonuclear research, nuclear power reactors, high energy physics and nuclear physics, neutron physics, and the structure of the nucleus; exchanges of documents, reports and abstracts; and exploration of the feasibility of joint projects.

List of Countries with which There Exists Formal Arrangements for International Cooperation with the USSR in the Field of Atomic Energy

"Research" Agreements for Cooperation

Country	Date of Agreement
Rumania	4/22/55
Poland	4/23/55
Czechoslovakia	4/23/55
China	4/27/55
East Germany	4/28/55
Hungary	6/13/55
Yugoslavia	1/28/56
Egypt	7/12/56
Indonesia	(Under discussion)
Bulgaria	
North Korea	
Iraq	8/17/59

"Power" Agreements and Offers of Power Assistance

Country	Date of Agreement
East Germany	June 1956
Czechoslovakia	January 1957
Poland	
Hungary	
India	(Under discussion)

"Reciprocal" Exchange Arrangements

Country	Date Signed
United States	11/21/59
France	4/1/60

C. Nuclear Developments in Other Bloc Countries

Although there were some attempts to initiate nuclear research programs in certain Soviet Bloc countries of Eastern Europe before 1955, little progress was made due to the lack of materials and manpower. Assistance has been provided for under agreements for cooperation with the USSR, as well as through international conferences attended by Western scientists, and through the IAEA.

In the spring and summer of 1955, the Soviet Government concluded research agreements with Rumania, Poland, Czechoslovakia, East Germany, and Hungary, as well as Communist China. This led to the organization of more formal programs and subsequent construction of new research centers. Today, each of the Soviet Bloc countries of Eastern Europe (except Albania), as well as Communist China, has at least one national nuclear research center with a research reactor and cyclotron purchased from the Soviet Union.

Beginning in 1956 certain Eastern European countries and China started to plan nuclear power programs with Soviet assistance. "Power" agreements were concluded by the USSR with East Germany and Czechoslovakia. In addition, the Soviet Government also offered to assist certain other nations. The first nuclear power stations to be completed under these agreements is, as noted previously in this report, expected to go into operation in East Germany in 1961. Other Eastern European nations are expected to follow with their first nuclear power stations during the next decade.

Endowed with reserves of uranium, but poor in technical know-how, China and Eastern European members of the Bloc must improve their power production if they are to keep pace with industrial goals. Conventional resources will therefore have to be supplemented in the sixties with nuclear power.

Personnel to operate these stations are being sent to the Soviet Union and other countries for training in the utilization of this new equipment, as well as in nuclear research and isotope application. It is also anticipated that additional help will come from radio-isotopes, which are now being produced with the Soviet-built research reactors and are being used increasingly in all phases of the national economies.

Although the Eastern European members of the Bloc, who had suffered so much from participation in World War II, were late in establishing atomic energy programs, much progress has been made in raising the technological level of the country. As this level is raised further, and uranium reserves developed, atomic energy may be expected to play an increasingly important role in the national economies.

1. Albania

Smallest of the Soviet Bloc nations of Eastern Europe, Albania is the only one of the group which does not have any known uranium resources, an agreement for cooperation with the USSR, or an atomic energy program.

Although the Albanian Government did send delegates to the first Geneva Conference on Atomic Energy in 1955, indicating an interest in this development, she was not represented at the second and larger conference in 1958.

Atomic energy activities in Albania may thus be considered as restricted to her membership in the Joint Institute of Nuclear Research at Dubna and the International Atomic Energy Agency, in which there is a very limited participation, and the training of a small number of scientists in the USSR and at the Institute of Sciences in Tirana, the country's capital.

2. Bulgaria

Although not mentioned in the first group of countries offered atomic assistance by the Soviet Government, Bulgaria was subsequently offered and signed an agreement for cooperation with the USSR in June 1955. Shortly thereafter plans were made for a national research installation at Sofia, which would be centered around the research reactor and cyclotron to be purchased from the Soviet Union.

The reactor is a two megawatt (thermal) tank-type, capable of a flux of $1 \times 10^{13} n/cm^2/sec.$, and the cyclotron is a 25 Mev accelerator similar to those sold to other Bloc nations.

In July 1957 a Committee for the Peaceful Uses of Atomic Energy was established to direct the administration of the atomic energy program, reporting directly to the Council of Ministers.

Uranium has been found in a region 45 miles northeast of Sofia

and is estimated to be produced at a rate of about 1,000 tons of ore per day.

Nearly all training of students in the nuclear sciences and engineering are carried out at the Institute of Physics, Sofia, the Joint Institute of Nuclear Sciences at Dubna, and at the University in Sofia. Some students have been trained in the USSR in order to operate the reactor.

When the reactor is operational, much of the present needs of Bulgaria for radioisotopes will be provided for by the reactor. The utilization of isotopes, as in other Soviet Bloc countries, is being rapidly expanded in all major branches of the economy.

In addition to the "research" agreement for cooperation with the USSR and participating in the Soviet-led Joint Institute of Nuclear Sciences, Bulgaria is also a member of the International Atomic Energy Agency.

Although badly in need of additional sources of power, there has been no indication of plans for the use of nuclear power in the country for the next five years.

3. China

Despite the "special" position of China in the Soviet Bloc of nations, the atomic energy program of China is reportedly not as far advanced as some of the Eastern European countries of the Bloc.

One of the beneficiary nations of the Soviet offer of assistance of January 1955, China has purchased a limited amount of aid in the form of equipment, training and documentation. In return for such assistance

China has continued to ship uranium to the Soviet Union under the terms of the raw materials agreement of 27 March 1950 and subsequent agreements. Included among the Soviet equipment was a 7-10 megawatt (thermal) heavy water moderated research reactor, similar to that sold to Yugoslavia, and a 25 Mev cyclotron sold to five other Bloc nations. Both facilities went into operation in March 1958.

China is also one of the signatories to the Soviet Bloc agreement of March 1956 setting up the Joint Institute of Nuclear Research. Inasmuch as Communist China is not a member of the United Nations, she is not eligible for membership in the International Atomic Energy Agency. As the second largest contributor to the Dubna installation, China is assessed 20 percent of the cost. In return she is permitted to send a larger number of students to the Joint Institute than any other foreign country. A Chinese scientist, Wang Kang Chiang, is vice director of the Joint Institute.

In her intense drive toward industrialization, China is desperately trying to raise the level of power production in the country. At the end of the present Five Year Plan (1962), China hopes to be producing 40 to 43 billion kilowatt hours a year. The future plans of the country for utilization of nuclear power are not known, although the Soviet Union has reportedly offered nuclear power assistance to the Chinese Government.

4. Czechoslovakia

Long famous for the Joachimstal uranium mines, which were a

prewar source of radium, Czechoslovakia is today pressing vigorously ahead with an atomic energy program which makes her the most advanced technological nation of the Soviet satellites.

In 1945 the Czechoslovak and Soviet Governments signed a treaty giving the Soviet Union a share in Czechoslovak uranium for 20 years. Unlike the status of East Germany, which contributed a large amount of uranium to the Soviet Union in the form of reparation payments, Czechoslovakia was given a preferred status among the Soviet Bloc nations. In this position Czechoslovakia was reportedly the first Bloc nation to receive radioisotopes from the USSR and the first to be given access to Soviet technology when it was still classified. As a result, Czechoslovak scientists were in a better position to initiate their own nuclear research program.

In addition to utilizing radioisotopes, which had been done since 1951, scientists and engineers undertook a design study of the first nuclear reactor in 1953 and 1954. In 1955 the Soviet Government announced the availability of atomic energy assistance to Czechoslovakia and certain other members of the Soviet Bloc. Subsequently, the idea of constructing a nuclear research reactor was abandoned in favor of purchasing a research reactor from the Soviet Union. An agreement providing for the purchase of a research reactor and a cyclotron was signed with the Soviet Government on April 23, 1955.

Focal point for the administration of atomic energy activities in Czechoslovakia is the Institute of Nuclear Physics at Rez near

Prague, the national nuclear research center under the direction of Cestmir Simane. Direction of nuclear energy activities is coordinated with the overall guidance of the Academy of Sciences and the State Planning Commission.

The principal equipment at the Institute in the 2000 kilowatt (thermal) pool type research reactor and the 25 Mev cyclotron obtained under the terms of a bilateral agreement with the USSR. Designed primarily for physical and biological research and radioisotope production, the reactor has fuel elements enriched to 10% U-235 clad in aluminum and is capable of a maximum thermal flux of 2 x 10^{13} $n/cm^2/sec$. The reactor has been operable since September 1957.

The 25 Mev cyclotron has been delivered to the Institute, assembled, and went into operation on 21 January 1960.

Czechoslovak scientists at first received their training in the nuclear sciences and engineering in Moscow and other Soviet installations. After the Joint Institute for Nuclear Research was established at Dubna in 1956, Czechoslovak physicists were sent there to be trained in high energy physics, nuclear problems, neutron physics and other similar subjects. In addition, Czechoslovak scientists and engineers are being trained in reactor technology so as to enable them to operate Soviet-purchased equipment in their country. Charles University in Prague is also providing training in the nuclear sciences to overcome the lag in adequately trained manpower.

As in certain other countries of Eastern Europe which are attempting to raise the level of industrial production quickly,

Czechoslovakia's limited conventional sources of energy are forcing the Government to look to nuclear energy as an additional and replacement source of energy.

Consequently, the Czechoslovak Government, with the assistance of the Soviet Union, is embarking directly upon a program for the construction of one or more nuclear power plants primarily for power purposes. Following the Soviet example of building power stations where they will be required at industrial sites, Czechoslovak and Soviet scientists and engineers are assembling a Soviet-built natural uranium, heavy-water-moderated, gas-cooled reactor capable of generating 100 megawatts electrical power at Bohunice, east of Trnava in Slovakia. Natural uranium for the fuel elements is being provided by Czechoslovakia and manufactured in the USSR. Heavy water and other nuclear materials for the reactor are expected to come from the Soviet Union.

The Bohunice nuclear power station is reported to be the first of ten nuclear power stations, which are intended to add a total nuclear generating capacity of 5000 megawatts to the national economy by 1970. In order to provide for the nuclear materials needed for the Czechoslovak program in the future, the Government is building a uranium processing plant and a heavy water production plant.

Czechoslovakia is also a member of the International Atomic Energy Agency and the Joint Institute of Nuclear Research.

5. East Germany

As part of a defeated nation, the Soviet occupation zone of Germany, which later became known as the German Democratic Republic or East Germany, made two significant contributions to the atomic energy program of the USSR.

When knowledge was obtained in 1946 of the rich deposits of uranium in the Ore Mountains and in the Thuringian Forest, the Soviet Government established a Soviet-controlled company, Wismut A. G., to supervise the exploitation of the field and shipment of the concentrates to the Soviet Union as reparation payments. As additional discoveries of uranium were made, Wismut A. G. became in 1953 a joint USSR-East German company.

A second East German contribution to the Soviet program, although difficult to evaluate, was the employment of East German scientists in the program of the USSR following their capture or recruitment in 1945 and 1946. Among those scientists were Gustav Hertz and Heinz Barwich and Manfred von Ardenne, each capable in his field.

Following signature of the "research" type agreement for cooperation with the Soviet Union on April 28, 1955, and the first large scale revelation of atomic energy data at the Geneva Conference of August 1955, the Government of East Germany established a Scientific Council for the Peaceful Utilization of Atomic Energy. The Council, which was located at Dresden, comprised 21 members from scientific and

academic institutions. Gustav Hertz was named Chairman. The purpose of the Scientific Council is to advise the Council of Ministers on all matters concerning the development of nuclear energy in East Germany. Subsequently, the Office for Nuclear Research and Technology, a government agency directly responsible to the Council of Ministers, was created under the direction of Karl Rambusch to coordinate and administer the nuclear energy program of East Germany.

Although the East German AEC is situated in the eastern section of Berlin, the principal research center, the Central Institute for Nuclear Physics has been constructed at Rossendorf, near Dresden. Director of the Institute is Dr. Heinz Barwich. Following his release from a British prison in 1959, where he served a term for espionage, Klaus Fuchs was appointed to the position of Deputy Director of the Institute. A second nuclear research center may be established at Rostock to study the application of nuclear energy to propulsion, particularly for merchant vessels.

The Central Institute at Rossendorf is the recipient of the reactor and cyclotron purchased by the East German Government from the Soviet Union. Similar to the Czechoslovak, Polish and Rumanian research reactors, the East German is a 2 MW (thermal) pool type capable of a maximum flux of 2 x 10^{13}n/cm^2/sec. with aluminum clad fuel elements enriched in 10% U-235. In addition to the 25 Mev cyclotron, the Institute also possesses laboratories for radiochemistry, electronics and solid state physics.

As in the case of its larger Western counterpart, East Germany was not permitted to become involved in nuclear energy activities for the first ten years following the war due to an Allied occupation statute. The ten year lag seriously affected the manpower situation, which became evident when East Germany established its program in 1955. One of the first tasks was therefore the training of an adequate number of scientists and engineers. Although a number of scientists had returned to East Germany from employment in the Soviet program, most scientists went to the Western part of the country. The important scientists who did return formed the cadre of the East German program centered around Dresden, where the Technical Institute gives courses in reactor engineering and isotope techniques.

East Germany has also taken advantage of its ties with the USSR to train specialists in that country to operate the research reactor, cyclotron, power reactor and other equipment purchased from the Soviet Union. As a member of the Joint Institute for Nuclear Research, East Germany is able to train her scientists in high energy physics and other related work at Dubna.

If East Germany is to continue to raise the industrial level of the country, the government will have to increase the power output of the country nine percent a year to meet this demand. Sources of fossil fuels, primarily lignite, may be expected to be exhausted by the end of this century. Lignite deposits are estimated at 50,000-

60,000 million tons, mostly in the Senftenberg district. There are no known natural gas deposits in East Germany. Oil is not produced in commercial quantities. When lignite production levels off at about 350 million tons a year by 1970, the East German government expects to have 3,000 megawatts of installed electrical generating capacity in operation.

With the assistance of the USSR, obtained under a "power" bilateral agreement for cooperation signed in June 1956, East Germany is constructing a heavy water moderated, gas-cooled power reactor at Neuglobsow on Stechlinsee, 45 miles north of Berlin. Both the natural and enriched uranium to be utilized as fuel for the reactor are being obtained from the USSR. The reactor, which is scheduled to be completed in 1961, is expected to produce 250 megawatts of heat and 70 megawatts of electricity. Later, a second stage reactor is expected to produce up to 150 electrical megawatts. A second nuclear power station of 100 MWe capacity is to be built in the neighborhood of Lake Malchin by 1964.

6. Hungary

The birthplace of such nuclear scientists as Von Neumann, Teller, Wigner, Szilard and de Hevesy, who left the country because of Nazi oppression, Hungary today looks to atomic energy as a means of curing at least one of her important economic ills -- a shortage of power for an economy attempting to industrialize.

Considered by the Soviet Union as a defeated Axis partner of

World War II, Hungary received little outside assistance in attempting to establish an atomic energy program until 1955, although a good source of uranium had been reportedly discovered near Pecs during the previous year and was later being shipped to the Soviet Union.

Despite this lack of assistance and the shortage of adequately trained manpower and equipment, the Hungarian Academy of Sciences decided to establish a Central Institute of Physical Research at Csilleberg, near Budapest, in 1950. The Institute operated with minor laboratory equipment, doing some work on nuclear physics, cosmic radiation and radiochemistry. In 1954 the Pecs uranium discovery occurred and the Hungarian Academy established a second center, the Institute of Nuclear Research at Debrecen, which would include research on uranium extraction processes so that Hungary could process her own ore. An agreement for cooperation with the USSR, providing for the purchase of a 2 megawatt pool type reactor and other technical assistance, was signed in June 1955. An eleven man Atomic Energy Committee was created by the Government in January 1956 to formulate plans for and direct the implementation of a nuclear energy program for the country. Two months later Hungary signed the accord making her a member of the Joint Institute of Nuclear Research at Dubna, for which she was to pay four percent of the costs.

The Hungarian revolution of October 1956 and its after effects brought atomic energy developments almost to a halt. Ukranium mines, which were being worked for the Soviets and which was one of the sources of discontent, were occupied by the revolutionaries. Work at the nuclear research institutes stopped, including work on the country's first research reactor, purchased from the USSR. Training of students was interrupted and a mass investigation of the loyalties of the community, including those persons in the atomic energy program, occurred.

In 1957 the atomic energy program returned to normal, with some exceptions. Lajos Janossy, a highly respected cosmic ray physicist, who returned from Great Britain in 1950, was appointed director of the Central Institute. Under his administration, work on the installation of the Soviet-manufactured research reactor continued. The Atomic Energy Committee was also reorganized and Antal Arpo appointed Chairman. Uranium exploration in other parts of Hungary was also renewed in the same year.

One of Hungary's most pressing problems is the training of an adequate number of personnel for the atomic energy and future nuclear power program. Some scientists and technicians have been trained in other countries, but this has been too limited in number. An attempt is being made to expand the domestic facilities of the country at the two Institutes of Nuclear Research and at the University of Budapest,

where a Department of Nuclear Physics has been established.

The research reactor, which is also being used for isotope production at the Central Institute, went into operation in October 1958. A second research reactor is also expected to be installed at the Institute at Debrecen.

In addition to a bilateral agreement with the USSR, Hungary is also a member of the Joint Institute of Nuclear Research at Dubna and the International Atomic Energy Agency.

7. Poland

As with other nations of Eastern Europe, the atomic energy program of Poland was established in 1955 after the signing of an agreement for cooperation with the USSR.

After studying the organizational needs of the program, the Polish Academy of Sciences appointed a Council or Committee on the Peaceful Uses of Nuclear Energy to act as a general advisory committee to the Academy on atomic energy matters. In addition, a permanent governmental body, the Federal Commission for Nuclear Energy Affairs, was created to direct, plan and administer the nuclear program. Mr. Wilhelm Bellig, a capable government administrator, was appointed to direct the agency, with the rank of Minister.

Scientific direction of the Polish program is under the Institute of Nuclear Research, of which Professor Nowacki is director. Carrying out the research and development work are three centers in the country at Swierk, Zeran and Bronowice.

The nuclear research center at Swierk (30 km south of Warsaw),

under the direction of Professor Nowacki, houses the 2 megawatt pool-type research reactor, in addition to a 10 Mev linear accelerator and physics and electronics laboratories. At Zeran (10 km north of Warsaw) is the applied research center, which is the focal point of isotope production and distribution in the country. There are also at the Zeran center a plutonium laboratory, a pilot plant for ore processing, a graphite manufacturing facility and an electronics laboratory. The third nuclear research center, at Bronowice (near Krakow), is a center for fundamental research in nuclear physics under Professor Niewodniczanski's direction. Equipment at Bronowice includes the 25 Mev cyclotron purchased from the USSR, and a 4 Mev cyclotron and 0.8 Mev Van der Graaff generator, both built by Polish scientists and engineers.

The Polish government also plans to build a second research reactor (a graphite moderated, gas cooled reactor using natural uranium as fuel), which would provide experience useful in the later operation of Poland's first nuclear reactor for the generation of electricity.

Due to her great supply of coal as a primary source of energy, the installation of nuclear power plants is not as urgent for Poland as it is for other Eastern European countries. In fact, from 1945 until 1956, when the political unrest occurred, Poland had been supplying much of the fuel requirements for Eastern Europe. During the period of optimistic enthusiasm for early competitive power, following the first Geneva Conference, Polish scientists argued for the early con-

struction of nuclear power plants on the basis that, among other reasons, the Polish coal saved could be exported to harder currency areas at higher prices, thus making nuclear power more economical. Ensuing political unrest and its resultant dislocation to the economy, the need to use investment for more urgent purposes, and the subsequent rising coal production in Western Europe caused Poland to delay plans for the construction of the first nuclear power station. A more cautious progress route to nuclear power therefore resulted.

Present plans of the Government now call for the construction of a large nuclear power station by 1965 capable of generating 200 megawatts of electricity from a graphite-moderated, gas-cooled, natural uranium fueled dual purpose reactor. Uranium for the reactor is expected to come from Poland, avoiding the necessity of relying upon foreign sources of material. At the Second Geneva Conference, a Polish delegate cited future nuclear power goals as 800 megawatts of electrical installed capacity by 1970 and 1800 by 1975.

With regard to energy resources and nuclear materials for the national economy, Poland's future requirements may be met by existing conventional resources for the early future, and nuclear materials for the more distant future. Her hard and known coal reserves are one of Poland's great national assets, for she possesses about three-fourths of the reserves in Eastern Europe. Over 80% of Poland's energy is produced from coal. There is little hydro power and no oil. Uranium and thorium have been found in Polish granites and phosphates, the most

important deposits being in the regions of Walbrazych and Kladzko in southwest Poland. There are no ore processing facilities in Poland, so it is being shipped to the USSR. Poland does plan to build such a plant, however. In addition, Poland is attempting to produce nuclear grade graphite and hopes to build a graphite fabrication plant for its nuclear energy program.

A strong believer in international cooperation, Poland has utilized the assistance of other countries to improve the technical level of her atomic program. In April 1955, Poland signed a "research" agreement for cooperation with the USSR, providing for the transfer of equipment and other assistance in the establishment of the Polish atomic program. During the following year, Poland signed an agreement which gave her membership in the Joint Institute of Nuclear Research at Dubna, and she became a member of the International Atomic Energy Agency. Since that time her representatives have been active in both international organizations. An agreement for cooperation was signed with Yugoslavia in April 1957, and negotiations toward an agreement were held with several Western European nations, including France. The Soviet Union has also agreed to assist her with the construction of the experimental power reactor.

6. Rumania

Traditionally interested in the study of radioactivity, which was interrupted by her role in World War II as a member of the Axis powers, Rumania is attempting to improve the level of her technology

in the peaceful uses of nuclear energy to assist her in her plans of industrialization.

In 1955 the Rumanian Council of Ministers created a governmental committee to coordinate the national program for the development of atomic energy under the chairmanship of G. Gaston Marin. An Institute of Nuclear Physics was established in the same year with H. Hulubei as director to carry out nuclear research. The two megawatts tank type research reactor and 12.5 Mev cyclotron purchased under the terms of the agreement signed with the Soviet Union in April 1955, were installed at the Institute. An experimental 30 Mev cyclotron, a Van der Graaff generator, and a linear accelerator were also reported under construction.

Rumania's conventional energy resources presently consist of abundant oil reserves in the region of Ploesti on the Black Sea, a very limited deposit of coal, an undetermined potential of hydro power, and no known natural gas deposits. As in other eastern European countries, Rumania is attempting to increase industrial productivity levels and will have to look to nuclear energy as a power source. At the second Geneva Conference in 1958, a Rumanian delegate mentioned a national nuclear power goal of 500 electrical megawatts by 1975.

Deposits of uranium have been found in the western and northeastern sections of the country. A plant at Petrila, east of Petrosanc, extracts uranium from coal ash. In addition, the government plans to construct a uranium processing plant.

Radioisotopes, which are now being produced at the Institute of Nuclear Physics with the nuclear reactor, are being utilized in an increasing amount.

One of the biggest problems facing the Rumanian atomic energy program is the shortage of manpower to handle existing equipment as well as the future needs of the country. It is expected that much of Rumania's training needs may be handled through the country's association with the USSR by the bilateral agreement of 1955, the Joint Institute of Nuclear Research at Dubna, and the International Atomic Energy Agency.

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STAFF NOTE.—Information in the same vein as the foregoing was requested of other countries having atomic power programs and interests. Letters of request were sent to:

Hon. Lorne Gray, president, Atomic Energy of Canada, Limited, Ottawa, Canada

Hon. Yasuhiro Nakasone, chairman, Atomic Energy Commission of Japan, Tokyo, Japan

Dr. H. J. Bhabha, chairman, Indian Atomic Energy Commission, Bombay, India

The operative portions of these letters were as follows:

"1. A statement of your current views on the present and prospective state of technology in (*country*), with special emphasis on civilian atomic power—both fission and fusion. This would include details of present and prospective construction and operating costs—both for conventional and atomic power plants.

"2. A statement of the current plans of (*country*) for assisting, cooperating with or receiving assistance from other individual nations, and regional or international organizations, in forwarding the use of atomic energy for peaceful purposes.

"3. An appraisal of the manner in which you now believe atomic energy can best be utilized, both in the immediate and longer-range future, to achieve the objective of advancing science and technology, of raising the standards of living of peoples everywhere, and of improving the climate for international cooperation.

"It would be most helpful if the information requested could be available as quickly as possible. The final report of the review is scheduled for completion in June and will be forwarded for your information at that time. In order that your reply may be incorporated effectively, it would be appreciated if you could respond before the end of March. We appreciate that this may preclude the assembly of any totally new major report in this connection, and we believe that the data already readily available to you should suffice for our purposes. Where pertinent, it would be helpful if the data could be formulated on the same bases as that contained in the new U.S. AEC Ten-Year Program, with which I believe your staff is already familiar."

The various replies to these requests appears below.

EXCERPT FROM LETTER TRANSMITTING REPLY FROM CANADA

* * * * * * *

In response to your letter of 1st March, I am enclosing a statement for Mr. McKinney on Canada's atomic energy program. It is in three parts, dealing with the three subjects you listed.

* * * * * * *

REPLY FROM ATOMIC ENERGY OF CANADA LIMITED TO MR. ROBERT McKINNEY'S REQUEST FOR STATEMENTS ON CANADA'S ATOMIC ENERGY PROGRAM

1. ATOMIC POWER IN CANADA

Canada is well endowed with conventional energy resources. However, these resources are not uniformly distributed across the country and some regions will soon be running short of conventional sources of power close at hand.

The atomic power program in Canada is directed towards the specific needs of Canada and, in particular, is aimed at augmenting the production of electric power in those regions that will require supplementary sources of power in the near future. The first main area that will exhaust its indigenous conventional resources of power is the heavily industrialized part of Southern Ontario, and the Canadian atomic power program has, therefore, been focused on the needs of this area.

The Hydro-Electric Power Commission of Ontario (Ontario Hydro) is the electric utility serving this region. It is a publicly owned utility with a present generating capacity of about six million kilowatts. Atomic Energy of Canada Limited and Ontario Hydro have been working closely together for the past six years on the development of nuclear power stations for incorporating into the Ontario Hydro system.

Heavy Water Reactors

For nuclear power to be competitive in the Ontario Hydro system, the power must be produced at under six mills per kilowatt-hour, based on the financing arrangements available to Ontario Hydro. Careful and continual analysis of the various types of nuclear reactors being developed in the world's leading atomic energy countries shows that the natural uranium, heavy water moderated type of nuclear reactor offers the best promise for competitive nuclear power in Southern Ontario at the present time. Some of the reasons are:

(*a*) heavy water is the best reactor moderator

(*b*) using heavy water moderation, burnups of 10,000 megawatt days per ton can be achieved using natural uranium fuel, hence fuelling costs are very low

(*c*) no expensive uranium enrichment facilities are needed

(*d*) no expensive chemical processing plant is required to extract the remaining U^{235} contained in spent fuel as is necessary if enriched uranium fuel is used

(*e*) power costs are not dependent on an arbitrarily assigned credit for plutonium

(*f*) the spent fuel is stored "as is" and the waste disposal of highly radioactive solutions is avoided.

Those not in favour of the natural uranium heavy water system question the probable losses of heavy water and point out the relatively high capital cost of the plant. It is often not realized that the Canadian design assumes there will be some leaks of heavy water such as at valves and joints, but the whole reactor is enclosed in a vapour proof vault equipped with adequate vapour recovery equip-

ment. It is admitted that the capital cost of a natural uranium heavy water moderated plant is higher than that of some other types of plant but the higher capital charges are offset by lower fuelling costs. The Canadian system will, of course, be most attractive in circumstances where low financial charges are applicable, such as in Southern Ontario.

Power Program

While the first requirement in Canada is for large nuclear power stations of 200 megawatts and upwards, medium size plants in the range of 50–150 megawatts will be needed later, as well as small plants for remote sites. The AECL research and development program therefore includes work on medium and small size plants but at lower priority.

The Canadian nuclear power projects have evolved primarily from the basic work at Chalk River where the major pioneer work in the heavy water moderation system has been carried out. Chalk River is the foundation for the Canadian program not only for the physics of reactor systems but for the applied engineering and metallurgical aspects of reactor components, particularly the fuel. It is the magnitude and success of this work, coupled with the many years of operating large-scale heavy water research reactors that gives AECL designers the confidence they have in low fuel costs for the natural uranium heavy water systems.

The nuclear power projects sponsored by Atomic Energy of Canada Limited, and underway, are four in number—with a total final cost of perhaps $120 millions. These are supported by studies of other systems not considered to have advanced to the "project stage." The first project is the 20-megawatt (electric) Nuclear Power Demonstration (NPD) plant under construction near Rolphton, Ontario. The second is the 200-megawatt (electric) Douglas Point Station on the eastern shore of Lake Huron. These two projects may be coupled together, as they really form a prototype and a full-scale unit of basically the same design that is particularly applicable in the larger sizes. Both these stations use reactors of the heavy water moderated and cooled pressure tube type and will be fueled with natural uranium. The third project is a design study with associated development work on an organic cooled heavy water moderated reactor. The fourth project is a study of the application of the small-size pressurized water or boiling water enriched fuel reactor systems to Canadian conditions, particularly at remote northern sites.

NPD Station

NPD is progressing very well; it is virtually on schedule and the costs are following estimates as predicted. This plant should be near completion at the end of 1960 and should be operating by mid-1961. It is being designed and built by Canadian General Electric Company Limited for operation by Ontario Hydro as a joint undertaking with AECL. This project is not intended to be a commercially economic unit. It is a demonstration unit. It will demonstrate the reliability of operation of this system and the economics of the fuel cycle, and it will provide training for operators.

Douglas Point Station

The 200-megawatt Douglas Point project is going ahead without waiting for NPD to go into operation. This decision to proceed was based on the confidence of the design staff, the success of the NPD design, the success of the fuel development program at Chalk River, and on the realization that a full-scale plant must be built and operated before real costs of large stations will be known.

The plant is being designed and built by AECL. Ontario Hydro is assisting AECL and has selected the site. Clearing the site is in progress and construction will begin in mid-1960. The full cost of this station will be approximately $80 million including contingencies, escalation, interest during construction, engineering, and manufacturing development. Some components are already on order at fixed prices and this estimate is in line with the real costs obtained in the construction of NPD.

The initial unit fuel cost will be 1.11 mills/kWh but this will be lowered with the expected reduction in fuel element costs. Unit operation and maintenance costs at 80 percent load factor will be 1.02 mills/kWh. The net unit energy cost will depend on the actual interest rate experienced during construction and the lifetime interest rate in effect when the plant commences operation. In the Ontario Hydro system the net unit energy cost will be in the range of 6 to 7 mills per kilowatt-hour.

The layout of Douglas Point is such that a second 200-MWe unit can be added to the station at a later date, using common services and facilities. The savings in adding a second unit are substantial both in capital cost and in operating and maintenance costs and would reduce the net unit energy cost by 12 to 15 percent.

OCDRE Project

The third project, which may result in the construction of an organic cooled heavy water experimental reactor (OCDRE), is a contract with the Canadian General Electric Company Limited to continue the development of a reactor system they proposed. Due to the nature of the organic materials proposed for cooling, lower capital costs per kilowatt are expected and higher efficiencies due to higher temperatures are predicted, as compared to the heavy water cooled systems. On the other hand, fueling costs will be somewhat higher. This reactor system, if successful, should be particularly applicable to the medium sizes, 50–150 megawatts. In sizes of 200 megawatts and upwards, the neutron economy of the heavy water cooled reactors seems to have advantages that outweigh those of the organic materials. An active design and development program is under way at Canadian General Electric, coupled closely with development worked at Chalk River on organic materials. A decision to proceed with the final design and construction of a reactor of this type will be considered within the next year. The USAEC and Euratom are taking an active part in this program with interchange of staff and information and attendance at periodic joint meetings.

Package Reactors

The fourth project is primarily the compilation of information generated in the U.S. and made freely available to Canada by the USAEC. Canadian Westinghouse Company Limited have contracted to review

all the pertinent information on the small so-called package reactors which have been developed for possible application at remote sites. This type of plant, which utilizes fairly high enrichment, has been considered in detail, assuming the conditions of typical Canadian sites. The project is nearing completion and should be of specific interest to those concerned with the development and defence of the north.

Study projects of varying complexity and advancement are common in the Reactor Research and Development Division of AECL. Such systems as gas-cooled reactors have been studied and this line has led to the possibility of steam cooling a heavy water moderated reactor. This type of system looks promising but it is some years away and, even if pursued jointly with the U.K., it is unlikely that an experimental reactor would be proposed in less than two or three years.

2. INTERNATIONAL COOPERATION

There has been close cooperation between Canada and the United Kingdom and the United States since the early 1940's. In addition to visits, discussions, exchanges of documents and other normal means of cooperation, large joint experimental programs, such as the joint irradiation experiments at Chalk River, have taken place and are underway. This cooperation has been mutually of great benefit.

Owing to security restrictions, the same degree of cooperation was not possible with other countries until about five years ago when essentially all aspects of the peaceful uses of atomic energy became unclassified. In the last five years, cooperation between AECL and atomic energy organizations in other countries has been steadily growing.

This cooperation has not been limited to those countries with advanced atomic energy programs of their own but includes countries less advanced in atomic energy as well. A large number of technical experts from many countries visit AECL each year and AECL reports are automatically sent to thirty countries on an exchange basis.

Bilateral agreements for cooperation in the peaceful uses of atomic energy have been signed between Canada and the United States, West Germany, Switzerland, Japan, Australia and Pakistan. These bilateral agreements lay down the conditions under which exchanges of atomic energy information, materials and equipment can take place. The cooperation with other countries is on a less formal basis and is usually limited to cooperation in research and development.

Canada is represented in many international organizations dealing with atomic energy. Special mention should be made of the United Nations Scientific Advisory Committee in which the Canadian representative is Dr. W. B. Lewis, AECL's vice president, Research and Development.

Canada played an active role in the formation of the International Atomic Energy Agency and fully cooperating with the Agency. Along with the U.K., U.S., U.S.S.R. and France, Canada has one of the seats on the Agency Board of Governors for the five most atomically advanced countries. Two senior AECL staff have been released to take posts as Division Heads in the Agency.

An agreement for cooperation between Canada and the European Atomic Energy Community (Euratom) was signed in October 1959 and at the same time a technical agreement for cooperation was signed between Euratom and AECL which includes a joint program of research and development on heavy water moderated power reactors.

Canada's major project in the international field (and perhaps the largest single contribution any country has yet made) is the Canada-India reactor (CIR) which Canada has provided under the aegis of the Colombo Plan. The CIR is an improved version of the NRX reactor which has been so successful at Chalk River over the past thirteen years. Construction near Bombay has essentially been completed and the reactor will go critical in mid-1960. It will provide unique facilities for the training of scientific and technical personnel in India and from other countries including the Colombo Plan countries in South and South-East Asia. In addition to providing the reactor, Canada has made available extensive scientific and technical assistance to the project, including the training of Indian staff.

The provision of training facilities is a further contribution which is of inestimable value to countries that have not yet highly developed their scientific and engineering resources. At present there are attached to AECL to gain scientific and engineering experience thirty-two staff from outside Canada—not counting the fifteen staff from the U.K. and the fifteen staff from the U.S. A Reactor School has been established at Chalk River to give both Canadian and foreign scientists and engineers intensive twelve-week courses that emphasize the reactor technology developed by AECL.

3. UTILIZATION OF ATOMIC ENERGY

Atomic energy has three main applications—the production of power; the application of isotopes in agriculture, industry and medicine; and as a new research tool in the various scientific disciplines. In all these fields atomic energy has great promise.

In the production of power, the development, design and construction of nuclear power stations is an undertaking that can only be tackled by the more technically advanced countries. To date, no nuclear power station has been built which is economically competitive with a conventional power station of the same size. Extensive nuclear power programs are under way in the major countries of the world. The size of the program in a country has usually been based on the need for additional power in that country and the availability of money and of trained manpower. The construction of full scale stations is a necessary step in the development of economic nuclear power, but before building stations which will obviously not be economically competitive it is prudent to assess what technical knowledge will be gained by so doing. Certainly the expenditure of additional effort will hasten the day when nuclear power may be competitive, but again an assessment is necessary to determine whether the advantage gained is worth the additional effort. It is also clear that the advent of economic nuclear power will come about almost entirely by

efforts of the more technically advanced nations. When economic nuclear power stations have been proved, then they can be built in the less advanced countries if these countries need or want them.

There is already a wide application of isotopes in medicine, agriculture and industry. Those applications already developed are available for use in all countries in the world. For example, Cobalt 60 beam therapy units developed and manufactured in Canada are now installed in twenty-eight countries. Many new uses are potentially possible and it is particularly desirable to provide assistance to those countries that need help in the development of applications of particular importance to their social and economic welfare.

As a new tool in research, atomic energy is already being used to further the fund of basic knowledge in all scientific disciplines. This new tool, however, is mainly of value to existing scientific research institutions. The benefits to mankind arising from these scientific centres are of course not limited by national boundaries.

Of fundamental importance in the advancement of science and technology is a better understanding of the basic building blocks of the universe. Without a fuller knowledge of the elementary particles from which everything is made and of the forces interacting between these particles, we will not have the ability to make maximum use of nature for man's benefit. The continuing study of nuclear energy in the field of pure science is therefore of prime importance.

It is in these ways—the extension of the use of nuclear power when plants have been built and operated successfully and economically, the immediate extension of the application of isotope techniques where they can be of significant value, and the general broadening of knowledge to the benefit of mankind through new fields of research made possible by the discovery of atomic fission—that the applications of atomic energy will raise the standards of living of peoples everywhere.

Atomic energy developments both for peaceful and military purposes have brought in their train a great volume of international consultation and collaboration. Whether these developments have, in fact, helped to improve the climate for international cooperation is difficult to say. Military developments have at least given a new urgency to the necessity for international agreement on disarmament, and the very danger that they represent may be the compelling force leading the world towards international agreement on this issue.

International collaboration in the peaceful development of atomic energy has presented many difficult problems related primarily to safeguards against diversion to military uses. Through the International Atomic Energy Agency and bilateral agreements, Canada has played an active role in international cooperation in this field, and it has always been a matter of major concern to Canada to try to ensure, so far as possible, that atomic energy programmes intended for peaceful purposes are not diverted to military ends.

31st March, 1960.

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REPLY BY JAPAN FOR REFERENCE IN REVISION OF McKINNEY REPORT

I. PRESENT STATE OF ATOMIC ENERGY TECHNOLOGY IN JAPAN AND OUTLOOK ON FUTURE

(1) *Appropriations for Atomic Energy*

Japan is no exception to the worldwide trend for Government fund playing a big role in the field of atomic energy. Table 1 shows the atomic energy appropriations and their percentage in the science and technology budget as a whole since the inauguration of the Atomic Energy Commission.

TABLE 1.—*Atomic energy budget, appropriations for promotion of science and technology*

Year	Atomic energy budget	Budget for promotion of science and technology	Percentage
	Millions	*Millions*	
1956	¥2,020	¥11,971	16.9
1957	6,000	18,092	33.1
1958	7,793	20,905	37.2
1959	7,419	22,530	32.9

NOTE.—Even before the establishment of the Atomic Energy Commission, there were atomic energy appropriations in 1954 and 1955, too. These appropriations were for testing and research at national organizations, study of peaceful utilization of atomic energy on a commission basis, and subsidies, and amounted to ¥260,000,000 in the fiscal year 1954, and ¥200,000,000 in the fiscal year 1955.

In the atomic energy budget, the biggest in amount is the appropriation for the Atomic Energy Research Institute. This fact indicates that the Institute is playing a big role in Japan's atomic energy development. Other important appropriations are those for ore prospecting, mining and refining by the Atomic Fuel Corporation, expenditures of the Radiology Research Institute, atomic energy testing and research at national experimental and research organs and subsidies for private enterprises.

TABLE 2.—*Breakdown of atomic energy budget*

[In million yen]

	1956	1957	1958	1959	1960
1. Expenditures of Atomic Energy Research Institute	702	4,078	4,500	4,400	4,400
2. Expenditures of Atomic Fuel Corporation	100	651	1,250	1,130	1,230
3. Expenditures of Radiology Research Institute	0	144	569	583	702
4. A-energy testing and research at national institutions	325	509	672	553	515
5. Expenditure for testing and research on commission basis	0	81	200	160	126
6. Subsidies for testing and research	197	236	270	220	194
7. Bounty on prospecting for nuclear raw material	30	30	30	20	15
8. Measurement and survey of radioactivity	0	33	36	59	48
9. Purchase of nuclear raw material	2	60	65	96	267
10. Subsidies for radioactive waste disposal enterprises	0	0	0	14	3
11. Overseas trip of atomic energy experts	61	50	35	30	30
12. Others	*504	122	166	153	196
Total	2,020	6,000	7,793	7,419	7,726

NOTES

(1) The Radiology Research Institute was established in 1957.
(2) *This includes expenditures for research reactors in universities. (Other figures do not include appropriations for testing and research at universities.)
(3) The Electric Power Resources Corp's. (special corporation) investment in the Japan Atomic Power Co. is not included.
(4) The Education Ministry's science research fund is allocated for research at national universities and their laboratories. The amount of this fund allocated during the period from 1954 to 1959 is as follows:

Allocation of Education Ministry's science research fund related to atomic energy

	1954	1955	1956	1957	1958	1959	Total
Physics	1,665	29,600	52,915	40,420	56,780	36,140	217,520
Chemistry	4,490	20,300	18,645	43,180	19,180	29,460	135,255
Reactor		1,230	11,290	8,500	10,620	8,290	39,930
Nuclear fuel, material		20,950	34,600	33,580	36,750	35,010	165,890
Nuclear fusion				5,000	22,860	29,300	57,160
Utilization of RI	3,080	9,235	4,080	4,440	2,730	10,800	34,365
Radiation injury	4,340	14,080	20,060	19,460	25,840	22,720	106,500
Total	13,575	95,395	141,590	159,580	174,760	171,720	756,620

A chronological breakdown of the testing and research appropriations listed in items 4, 5 and 6 in Table 2 is shown in Table 3 (attached) [pp. 1386–1396].

(2) *Private Fund in Atomic Energy Development*

Development of atomic energy is being pushed forward by private enterprises, besides the organizations established and being operated on the Government's funds, such as the Atomic Energy Research Institute, Radiology Research Institute and Atomic Fuel Corporation. Today, almost all leading enterprises in various fields are taking part in the utilization and development of atomic energy in some form or other. There is, however, a wide variety in the scale and extent of their participation in utilization and development of atomic energy—some enterprises already have experience in the construction of atomic reactors while others are not going beyond utilizing radiation rays on a small scale—and we cannot say for sure what amount of private fund is contributing to atomic energy study and development.

Table 4, however, shows private investment in the Atomic Energy Research Institute and the Japan Atomic Power Company, and also the capital funds of the atomic industrial companies inaugurated since the end of 1957.

Besides, as enterprisers' groups organized by existing enterprises for the development of atomic energy, there are the Tokyo Atomic Industrial Consortium, the First Atomic Power Industry Group and the Tokyu Atomic Energy Research Group.

TABLE 4

[In million yen]

	1956	1957	1958	1959	1960
Private investment in Atomic Energy Research Institute	248	258	287	250	250
Private investment in Atomic Power Co.[1]	----------	800	----------	800	----------
Capital fund of Sumitomo Atomic Industries Co.[2]	----------	125	----------	625	----------
Capital fund of Nippon Atomic Industrial Group Co.[3]	----------	----------	500	----------	----------
Investment in Mitsubishi Atomic Industries Co.[4]	----------	----------	500	----------	----------

[1] Investment for the establishment of the Japan Atomic Power Co. was made from private circles and from the Electric Power Resources Development Corp., which is a special corporation financed by the Government, at a ratio of 8 to 2.

[2] The Sumitomo Atomic Industries Co. was established with investment made by 14 companies of the Sumitomo affiliation. The original purpose of the company was utilization of radiation rays.

[3] The Nippon Atomic Industrial Group Co. was established in September 1958 with joint investment by the companies of the Mitsui affiliation.

[4] The Mitsubishi Atomic Industries Co. was established in April 1958, with joint investment by the companies of the Mitsui affiliation, for the purpose of designing, manufacturing, and selling atomic energy machines and instruments including reactors.

(3) *Installation of Reactors*

Construction and operation of JRR–1, which reached criticality in August 1957, and other reactors are being propelled mainly by the Atomic Energy Research Institute. Besides, approval has been given for the Japan Atomic Power Company's importation of a full-scale power reactor from Britain, and for the construction of reactors with private funds, such as by the Goto Scholarship Society. The designing and construction of the reactors of the Hitachi, Ltd. and the Tokyo Shibaura Electric Company will be subsidized by the Government. Except these two reactors and JRR–3, which will be designed and constructed by the Atomic Energy Research Institute, all other reactors will be imported from the U.S. or Britain.

TABLE 5.—*List of reactors (in operation, under construction, or planned)*

Installer	Location	Name	Purpose	Start of construction	Completion	Maximum output	Maximum thermal neutron flux (n/cm^2sec)
Atomic Energy Research Institute.	Tokai Village, Naka County Ibaraki Pref.	JRR–1 (water boiler type).	Basic research training	March 1956	August 1957 (In operation)	50 kilowatts	1.2×10^{12}
Do	do	JRR–2 (CP–5)	Basic research material test, isotope production.	November 1956	1959 (Under construction)	10 megawatts	1.2×10^{14}
Do	do	JRR–3 (home-made, No. 1).	Isotope production, engineering test, material test.	January 1959	1961 (Under construction	10 megawatts	2×10^{13}
Do	do	JPDR (boiling water type).	Experience in operation and maintenance, basic test, fuel test, etc.	1959	1962 (Pending negotiations on contract)	40 megawatts (electric output 12.5 megawatts).	2×10^{13}
Japan Atomic Power Co.	do	Calder Hall advanced type.	Power demonstration		October 1963 (Safety examination finished)	595 megawatts (electric output 159 megawatts).	2.83×10^{13}
Rikkyo University	Okusu-machi Yokosuka City.	TRICA–II	Research education		March 1961 (Safety examination finished)	100 kilowatts	1.6×10^{12}
Goto-Scholarship Society.	Kawasaki City	do	do		March 1961 (Safety examination finished)	100 kilowatts	1.6×10^{12}
Hitachi, Ltd		S.P. type	Research, education		1961 (designing)	100 kilowatts	3.2×10^{13}
Tokyo Shibaura Electric Co.		do	Training in research reactor making technics, physical study.		October 1960 (designing).	100 kilowatts	2.2×10^{11} (average)
Tokyo University		W.B. type	Research		September 1960 (plan).	10 watts	
Kansai group		S.P. type	do		March 1962 (plan)		
Kinki University (same as exhibited in International Trade Fair).		UTR type	do		July 1960 (plan)	0.1 watts	

TABLE 5.—*List of reactors (in operation, under construction, or planned)*—Continued

Name	Fuel	Moderator	Reflector
JRR-1 (water boiler type).	Uranium sulfate aqueous solution of 20 percent enriched uranium, U^{235} 1.3 kg.	Light water	Graphite, 9.5 tons.
JRR-2 (CP-5)	Plate-shape alloy of 20 percent enriched U and Al, U^{235} 4 kg.	Heavy water 9 tons (as reflector and moderator).	
JRR-3 (homemade No. 1).	Al-canned metallic U rod, natural U 6 tons.	Heavy water 25 tons.	Graphite, 80 tons.
JPDR (boiling water type).	Uranium of low concentration (U^{235} about 100 kg.).	Light water	Light water.
Calder Hall advanced type.	Natural uranium 185 tons	Graphite	Graphite.
TRIGA-II	Al-canned 20 percent enriched U (U-Zr-H alloy rod), U^{235} 2 kg.	Zirconium hydride	Do.
Do	20 percent enriched uranium (U-zr-H alloy), U^{235} 2 kg.	do	Do.
S. P. type	10 percent enriched U (uranium oxide ceramic), U^{235} 2.4 kg.	Light water	Graphite and light water.
Do	20 percent enriched uranium (U-Al alloy), U^{235} 3 kg.	do	Do.
W. B. type	Solved in homogeneous liquid		
UTR type	90 percent enriched uranium (U^{235} 264 g)	Light water	Graphite.

Name	Shield	Regulation	Coolant
JRR-1 (water boiler type).	Load and heavy concrete, 1.7 meters thick.	Shim rods, 3; regulating rod, 1.	Light water: Primary, 50 l/min. Secondary, 20–200 l/min.
JRR-2 (CP-5)	Six stainless steel plates, 2.4 centimeters thick, lead and heavy concrete.	Shim rods, 5; regulating rod, 1.	Primary cooling, heavy water; secondary cooling, light water.
JRR-3 (homemade No. 1).	Heavy concrete, 2 meters thick.	Shim rods, 12; regulating rod, 1.	Heavy water.
JPDR (boiling water type).	Light water, iron, concrete.	16 rods; toxious solution injected.	Light water.
Calder Hall advanced type.	Concrete	Shim rods, 18; regulating rods, 91; safety rods, 7.	Carbon dioxide.
TRIGA-II	Concrete, 7.5 feet thick	Boron carbide; regulating rod, 3.	Light water.
Do	Concrete, 7.5 feet thick	Regulating rods, 3	Do.
S.P. type	Upper: Concrete, 1.5 meters thick. Lower: Concrete, 2.45 meters thick.	Safety rods, 3; regulating rod, 1.	Do.
Do	Upper: Concrete, 2.6 meters thick.	Control strips, 3; regulating strip, 1.	Do.
UTR type		Regulating rod, 1; shim rod, 1; safety rods, 2.	Do.

(4) *Long-Term Program for Development of Power Reactors*

This program was mapped out on the basis of the outlook on the supply of electric power mentioned in the new long-term economic program of December 1957. It was aimed at improving the nation's foreign currency situation by economizing on imported fuel through atomic power generation to meet an increasing demand for power source, and at effecting a balance in the supply and demand of energy by making up for the dwindling trend in hydraulic power supply. According to the program, which was based on an optimistic outlook on the economy of atomic power generation, atomic power generation cost will be lowered to the level of the cost of thermal power generation using coal alone, and will become smaller than the cost of thermal power generation using heavy oil alone. In this way, the program set a goal at developing 7,000 MWC atomic power by the end of fiscal year 1975.

Later, necessity arose to make amendment to the long-term program on the development of power reactors, because estimation of atomic power generation cost became higher than that originally anticipated, and also because it became necessary to give some amendment to the long-term program on the supply and demand of energy, which was the basis of the power reactor development program. Revision of the long-term power reactor development program is expected to be completed within the year. Table 6 gives a comparison between the plan and the actual result in the fiscal years 1958 and 1959.

In 1958, according to this table, the actual record fell short of the planned level. As for total demand, the percentage of the actual record against the plan was 92.6%; as for demand for electric power, the percentage was 95.3%. In the fiscal year 1959, total demand and electric power demand increase by 12% and 14.2% respectively as compared with the figures in the preceding year, and were 96.8% and 100.2 percent respectively of the planned level. Although it might be too hasty to make a forecast on the basis of such a comparison alone, we can say that the plan for 1959 was considerably accurate if we regard the increase in demand in 1959 as having made up for the decline in demand which was recorded in the preceding year.

It is generally believed that the real cause for the necessity of revising the atomic power generation program lies in the recent trend in atomic power generation cost. Although Japan does not have experience in the construction and operation of power reactors nor does she have any reliable data on the economy of atomic power generation, according to the calculation made by the Atomic Power Company in March this year, the power generation cost of the Calder Hall type reactor, which is Japan's No. 1 full-scale atomic power reactor, is Y4.98 (however, if the period of durability is estimated at 20 years, an average power generation cost during this period is Y4.07 per KWH) as against Y4.40 to Y4.75 predicted in the long-term program. From an economic point of view, implementation of the atomic power generation program will probably be slowed down, since the cost of thermal power generation with the conventional type of power plants is rather on the downward trend. Anyway, revision of the power generation program will be the one which is to be balanced both by the trend for an increase in demand for energy resources and by the prospect for a decrease in atomic power generation cost.

TABLE 6.—*Comparison between energy supply-demand program and actual record*

(Not furnished with English text.)

(5) *Present Condition of Atomic Energy Scientists and Engineers*

The study and development of atomic energy in Japan was started in 1956 and proceeded rapidly, resulting in a shortage of scientists and engineers in this field. At the early stage, furthermore, most of these scientists and engineers had to study abroad because Japan did not have sufficient training facilities. Since 1958, however, education and training of atomic energy scientists and engineers in Japan have been gradually placed on the right track, with graduate schools of State universities opening atomic energy courses one after another. It was therefore considered necessary to investigate the pres-

ent condition of the atomic energy scientists and engineers in the industrial field, and to train them systematically on the basis of a concrete outlook on future demand for them. The following is the result of the survey conducted by the Atomic Energy Commission late in 1959 from this point of view.

Number of the scientists and engineers engaged in the study, development, or utilization of atomic energy, or in business concerning the machines, instruments and material necessary for these purposes (in principle, those who graduated from colleges under the former system or other schools of a higher level):

Private enterprises	2,478
Governmental testing and research organs	1,138
Universities	2,705
Total	6,321

These figures are as of the end of March 1958. According to their reports, private enterprises and Governmental testing and research organs want to have the membership of their scientists and engineers doubled by the fiscal year 1962, while universities need a 30% increase of such personnel to be realized by the same year.

The above-mentioned figures are not enough to be a basis for mapping out a training program, since they are a mere compilation of reports sent from various organizations concerned. The Atomic Energy Scientists Training Committee of the Atomic Energy Commission, therefore, made an estimation on the demand for atomic energy scientists and engineers for the fiscal year 1960 as shown in Tables 7–9 on the basis of a closer study and the long-term atomic power generation program. Table 6 shows the demand for scientists and engineers specialized in atomic energy and for scientists and engineers in the fields related with atomic energy. The scientists and engineers specialized in atomic energy in this table mean those who have a high level of knowledge and technique in the specialized fields of atomic energy, such as nuclear physics and nuclear engineering, and the scientists and engineers in the fields related with atomic energy mean those who have knowledge and technique in the specialized field of mechanics, electricity, physics, chemistry, etc. and require knowledge and technique in the specialized field of atomic energy.

In Table 7, the figures for the fields related with atomic energy are an estimation of the number of those who engage in basic and applied research on atomic energy in the Japan Atomic Energy Research Institute and other Governmental testing and research organs. The figures for atomic power generations are an estimation of the number of the scientists and engineers required by atomic power companies for the planning, construction, and operation of 150 MW atomic power generation equipment on the basis of the scale of atomic power generation as envisaged in the long-term program. Also in this table, the field of manufacturing atomic energy machines and instruments mean the private industries engaged in the designing and manufacturing of atomic power generation equipment, research reactors, particle accelerators, radiation measuring instruments, etc., and the field of prospecting for nuclear fuel resources, mining and the refining, fabricating and reprocessing nuclear fuel.

Table 8 shows the demand for scientists and engineers in the field related to the utilization of radiation rays. It assumed a number of working places in the fiscal year 1970, each of which having a legally qualified chief radiation engineer.

Table 9 gives the number of the engineers required for the safety control of atomic energy-utilizing facilities, calculated on the basis of the number of equipment expected to be built by the fiscal year 1970.

For the purpose of educating and training atomic energy scientists and engineers, atomic energy courses have been opened in national universities and their graduate schools one after another since 1958. The capacity for students in these courses in the fiscal year 1960 was 78 persons in the master-of-arts courses and 56 persons in the doctor courses.

Besides university education, the Japan Atomic Energy Research Institute has its Reactor Training Institute and Radioisotope Training Institute. Also, the Radiation Research Institute is going to organize a training division for the training of radiation ray safety control officers.

Since 1958, meanwhile, the Radioisotope Training Institute has been training foreign students under the fellowship programs of the UNESCO and the International Atomic Energy Agency. These students totaled 53 in 1958 and 1959 altogether.

TABLE 7.—*Estimation of demand for engineers specialized in atomic energy and for engineer in the fields related with atomic energy*

	Demand in 1970		Basis of calculation	
	(1)	(2)	(1)	(2)
Research fields related with atomic energy	500	1,500		
Field of atomic power generation: [1]				
Planning, ordering, work supervision	120– 150	750–1,000	8–10	50–70
Transportation	200	250–1,000	10	15–50
Subtotal	320– 350	1,000–2,000	18–70	65–120
Field of manufacturing atomic energy machines and equipment machines and instruments: [2]				
Atomic power generation	300– 350	3,000–3,200	20–25	200–220
Other machines and instruments (for RC)	100	500		
Research	150	150		
Subtotal	550– 600	3,650–3,850		
Field of nuclear fuel: [3]				
Prospecting, mining, primary refining [3]	5	170–250		
Final refining	10	130		
Fabricating processing	50	50–150		
Retreatment [4]	15	50–70		
Research	80	80–160		
Subtotal	160	480–760		
Total	1,530–1,610	6,630–8,110		

[1] Number of personnel required in the case of a 150 megawatt atomi power plant (in 1970): Operation, 20; construction, 15.
[2] Number of personnel required for designing and constructing 150-megawatt atomic power generation equipment (under construction in 1970), 15.
[3] 150 t/y equipment, 1,000 t/y equipment.
[4] 100–200 t/y equipment.

NOTE.—The figures for 1970 do not necessarily coincide with the result of calculation from the "basis of calculation," since small fractions in the figures were cut down or raised to a higher unit.

TABLE 8.—*Estimation of number of working places handling radioisotopes*

	Present number of working places	Estimation for 1970
Research organ	77	163
Private enterprise	200	344
Hospital	238	543
Subtotal	515	1,050
Related to university	200	209
Total	715	1,259

TABLE 9.—*Number of radiation safety control officers required*

Type of facilities	Present number (including plan)	Estimation for 1970 (number of of control officers required)
1. Reactor equipment for research	3	10×2 persons= 20 persons.
Reactor equipment for power generation	0	20×2 persons= 40 persons.
2. Refining and processing of nuclear fuel material	1	10×2 persons= 20 persons.
3. Particle accelerating equipment	37	50×1 person = 50 persons.
4. Facilities equivalent to Co^{60} 1,000 C	30	60×1 person = 60 persons.
5. Large-scale RI-utilizing facilities	33	60×1 person = 60 persons.
6. Waste disposal facilities	1	5×1 person = 5 persons.
7. Other related facilities (fuel treatment, RI distribution, etc.).	0	20×2 persons= 40 persons.
Total	105	235 295

NOTE.—We assumed that 1 or 2 persons will be assigned to each equipment as mentioned in this table, although it is extremely difficult to predict the required number of radiation safety control officers to be assigned to each type of equipment.

ATOMIC ENERGY COURSE ESTABLISHMENT PLAN IN STATE UNIVERSITIES

1. Graduate courses in universities

University	Major	Capacity for students in M.A. course
Opened in 1957:		
Tohoku University	Nuclear science	10
Tokyo Institute of Technology	Nuclear engineering	10
Kyoto University	do	10
Osaka University	do	10
Opened in 1958:		
Tohoku University	do	10
Tokyo University	Mathematics-physics course, chemistry course, biology course.	18
Kyoto University	Nuclear science	

2. Undergraduate course in university

University	Department	Number of students admitted
Opened in 1958: Kyoto University	Nuclear engineering course, engineering department.	20
Opened in 1960: Tokyo University	Atomic energy engineering course, engineering department.	36

3. Lecture course, section

University	Department, laboratory	Lecture course, section
Hokkaido	Engineering department	(Applied nuclear physics.) Reactor engineering.
Tohoku	Science department	(Applied nuclear physics.) (Nuciar spectroscopy.) (Radiation chemistry.)
	Engineering department	(Reactor engineering.) (Radiation metrology.)
	Metallic material laboratory	(Rare metal.) (Radiation metal chemistry.) (Reactor material, metallography.) (Reactor material processing.)
	Laboratory of concentration and refinery.	(Atomic nucleus fuel metallurgy.)
Tokyo University	Science department	(Radiation chemistry.) (Nuclear reaction physics.) Plasma physics.
	Engineering department	(Reactor engineering.) (Reactor material.) (Radiation metrology.)
	Medical department	Radiation health control.
Tokyo Institute of Technology.	Reactor research facilities	(Reactor physics.) (Reactor engineering.) (Radiation metrology.) (Radiation chemistry.) (Reactor material.) (Nuclear chemical engineering.) Radiation protection.
Nagoya University	Engineering department	(Applied atomic nuclear engineering.) Reactor engineering.
	Plasma engineering research facilities.	Plasma apparatus.
Kyoto University	Science department	(Nuclear energy science.) (Nutron physics.) (Radiation biology.)
	Engineering department	(Nuclear reaction engineering.) (Isotope engineering.) (Reactor engineering.) (Reactor material.) Reactor machines and instruments.
	Chemical laboratory	(Nuclear reaction.) (Radiation chemistry.)
	Engineering laboratory	(Reactor construction.) (Reactor chemical engineering.) (Reactor material.) (Reactor fuel.) (Reactor metrology.) (Reactor safety engineering.) (Radiation ray application.)
Osaka University	Science department	(Radiation chemistry.) (Nuclear reaction physics.)
	Engineering department	(Reactor engineering.) (Reactor material.) (Nuclear machines and instruments.) (Reactor chemical engineering.) (Ultra-high temperature engineering.)
	Industrial Science Institute	(Radiation applied measurement.) (Radiation applied processing.) (Radiation food.) (Radiation high polymer chemistry.)
Kyushu University	Engineering department	(Applied nuclear physics.) Reactor engineering.

Number of lecture courses and sections

Already established	49
Expected to be established in fiscal 1960	10
Total	59

4. Expenditures (new budget for fiscal 1960)

[In thousands of yen]

Item	Amount	Breakdown	
		Running expenses	Cost of installation
Lecture courses, sections	416,869	36,169	380,700
Reactor for Kansai District	(240,000)		(240,000)
	100,000		100,000
Total	516,869	36,169	480,700

II. INTERNATIONAL COOPERATION

(1) *Bilateral Agreement*

General agreements have so far been concluded with the U.S., Britain, and Canada for international cooperation in the field of peaceful uses of atomic energy. Under these agreements, research or power demonstration reactors JRR–1, and JPDR are imported from the U.S. and the Calder Hall improved type reactor from Britain, and also the special nuclear material, nuclear fuel material, uranium concentrate and heavy water as shown in the table have been, or are expected to be, imported.

Also Japan has been affiliated with the International Atomic Energy Agency since its inauguration, and bought from the Agency 3 tons of metallic uranium as the fuel for JRR–3. The special nuclear material and other materials obtained under the agreements are as follows:

(i) Special nuclear material (enriched uranium)

When obtained	Obtained from—	Concentration	U^{235} (g)	Type	User (purpose)
		Percent			
May 24, 1957	U.S.A	19.91	1980.0	$UO_2SO_4.3H_2O$	Atomic Energy Research Institute (fuel for JRR–1).
		18.27	.57	U_3O_8	Atomic Energy Research Institute (fission chamber).
Mar. 25, 1958	do	20	1.032	U_3O_8	Do.
May 25, 1959	do	19.3	.332	U_3O_8	Do.
		20	15		Semihomogeneous (critical facility).
		20	2		Aqueous-homogeneous (critical facility).
		20	3		Atomic Energy Research Institute (fast breeder exponential experiment).
Planned (April 1960 to March 1961).	do	20	2.3		Goto Scholarship Society (fuel for TRIGA–2).
		20	2.3		Rikkyo University (fuel for TRIGA–2).
		20	3.5		Toshiba (fuel for swimming pool) reactor).
		10	4.0		Hitachi, Ltd. (fuel for swimming pool reactor).
		90	3.5		Kinki University (fuel for UTR).
		90	3.5		Tokai University (fuel for UTR).
		20	8		Atomic Energy Research Institute (2d and 3d inventory for JRR–2).
		1.5	32.5		Hitachi, Ltd. (BWR critical facility).
		25	11.3		
	U.S.A.	2.6	146		Atomic Energy Research Institute (JPDR).
	U.S.A.	2.6	40		Atomic Energy Research Institute (BWR critical facility).

(ii) Nuclear fuel material obtained under agreements

When obtained	Obtained from—	Name of element	Type	Quantity (in terms of U, kg.)	User (purpose)
Feb. 15, 1957	U.S.A.	U	$UO_2U_3O_8$	325.0	Atomic Energy Research Institute (for research).
Dec. 15, 1957	U.S.A.	U	UO_2	150.0	Do.
Apr. 15, 1958	U.S.A.	U	$UO_3(NO_3)_2$	20.0	Do.
		U		50.0	Atomic Fuel Corp. (for research).
		U		99.0	Sumitomo Metal Industry Co. (for research).
		U	$UO_3(NO_3)_2$	12.1	Osaka Metal Industry Co. (for research).
November 1958	U.S.A.	U	$UO_2(NO_3)_2$	60.4	Physics & Chemistry Research Institute (for research).
December 1958	U.S.A.	U	UO_2	35.2	Mitsubishi Atomic Industries Co. (for research).
1958 (2d quarter of the fiscal year).	U.S.A.	U	$(NH_4)_2U_2O_7$	22.9	Sumitomo Electric Co. (for research).
February 1959	U.S.A.	U	$(NH_4)_2U_2O_7$	15.3	Do.
1958 (2d quarter of the fiscal year).	Canada	U	$UO_2(NO_3)$	35.3	Physics & Chemistry Research Institute (for research).
Do	do	U	$UO_2(NO_3)$	59.8	Asahi Electro-Chemical Co. (for research).
Do	do	U	$UO_2(NO_3)$	27.2	Yokozawa Chemical Co. (for research).
March 1959	do	U	U	100.0	Hitachi, Ltd. (for research).
April 1959	do	U	U	20.0	Furukawa Electric Co. (for research).
1960	IAEA	U	U	3,042.0	Atomic Energy Research Institute (fuel for JRR-3).

(iii) Uranium concentrate (U_3O_8) obtained under agreements

When obtained	Imported from—	Quantity (in terms of U_3O_8, kg)	User (purpose)
May 1957	Britain	100	Atomic Fuel Corp. (for research).
July 17, 1958	United States	50	Do.
April 1959	do	300	Mitsubishi Metal Mine Co. (for research).
August 1959	do	618	Do.
February 1960	do	2,000	Atomic Fuel Corp. (for testing).
July 17, 1958	Canada	573	Atomic Fuel Corp. (for research).
June 1959	do	227	Sumitomo Metal Mine (for research).
August 1959	do	6,000	Atomic Fuel Corp. (for refinery).
February 1960	do	6,500	Do.
Do	do	227	Sumitomo Metal Mine Co. (for research).

(iv) Thorium obtained under agreements (ThO_2)

When obtained	Imported from—	Quantity (ThO_2 kg)	User (purpose)
June 15, 1959	United States	282.29	Atomic Energy Research Institute (for research).

(v) Heavy water obtained under agreement

When obtained	Imported from—	Quantity (D_2O pound)	User (purpose)
Aug. 27, 1959	United States	20,000	Atomic Energy Research Institute (moderator for JRR-2).

(2) *International Cooperation in Atomic Energy Technology*

(i) Construction of Atomic Reactors: Although the main contractors on the reactors, which have so far been installed or which are now being installed, except JRR–3, are foreign makers, some of Japanese makers have contributed or are contributing with them as follows:

JRR–1 Japan Atomic Energy Research Institute:
Main contractor: North American Aviation Co. (NAA).
Participating Japanese companies and assignments to them:
Hitachi, Ltd.: Installation of reactor proper, assembling, piping.
Mitsubishi Japan Heavy Industries Co.: Experiment facilities.
Japan Cement Co.: Shield material.
Mitsubishi Electric Appliance Co.: Electric wiring.

JRR–2 Japan Atomic Energy Research Institute:
Main contractor: American Machine Foundry Co. (AMF).
Participating Japanese companies and assignments to them:
Mitsubishi Shipbuilding Co.: Heavy and light water system piping, and fittings (reactor proper).
Mitsubishi Kako Co.: Experiment facilities, cooling tower.
Mitsubishi Electric Appliance: Helium system piping and fittings. Pneumatic system piping and fittings (pump room). Electric wiring.
Mitsubishi Japan Heavy Industries Co.: Pneumatic system piping and fittings (reactor proper). Outer plate and other structure of reactor proper.
Shin Mitsubishi Heavy Industries Co.: Thermal shield.
Mitsubishi Atomic Industries Co.: Installing.

JRR–3 Designing and construction of the reactor were undertaken by Japanese makers. Processing of fuel alone will be done by the Canadian AMF.

Calder Hall Advanced Type Reactor:
Main contractors: GEC group, General Electric Co., Simon-Carves, Ltd., Motherwell Bridge & Engineering Co., John Mowlem & Co.
Assignments to Japanese companies:
Fuji Electric Co.: Pressure vessel, piping, assembling, installing, electric wiring.
Kawasaki Heavy Industry Co.: Heat exchanger, condenser.
Kobe Steel Mfg. Co.: Gas supply device.
Ebara Mfg. Co.: Waste disposal apparatus.
Shimizu Construction Co.: Civil engineering.
Total construction cost of powerplant: About ¥35 billion.
Cost of reactor proper: About ¥20 billion (of which, home-produced part about ¥8 billion).

(2) *Technical Cooperation*

The following is an outline of the technical cooperation with foreign reactor makers approved on or before December 1, 1959:

Applicant	Foreign company	Techniques
Atomic Fuel Corp	Cox & Weinrich (United States).	Interim testing equipment for making metallic uranium.
Japan Atomic Energy Research Institute.	Kaiser Engineering Division of Henry J. Kaiser Co. (United States).	Survey and technical data concerning purex and thorex process.
Do	Arther D'Little, Inc. (United States).	Technical guidance for design of radioactive solid waste buring apparatus.
Do	Inter Nuclear (United States).	Examination of AFRI's specifications for PDR, and advice.
Furukawa Electric Industry Co.	Catalytic Construction Co. (United States).	Preliminary technical data concerning uranium refining.
Atomic Fuel Corp	Weinrich & Associates (United States).	Moving-floor type ion exchange refining apparatus for crude refining, and drawing.
Sumitomo Metal Mining Co.	Degussa (West Germany).	Technical information required for preliminary test on making uranium metal and uranium compound from refined uranium ore.
Japan Atomic Power Co.	AEA (United Kingdom).	Technology concerning construction, operation, and maintenance of atomic powerplant.
Atomic Fuel Corp	Weinrich & Associates (United States).	Survey and data concerning fuel retreatment.
Showa Denko Co	Centre National de la Recherche Scientifique.	Information and guidance on basic technique for making graft polymer by radiation ray.

The following is a list of the technical cooperation items under negotiation:

	Application submitted		Pending negotiations
Japanese company	Fuji Electric Co	Mitsubishi Atomic Industries Co.	Hitachi, Ltd.
Foreign company	GEC	Westinghouse	GE.
Reactor type	All types to be developed by GEC, GCR, and others.	All types to be developed by Westinghouse.	Types with which GE has experience.
Scope	Atomic energy part of atomic energy plant.	From fuel processing to steam evaporation.	From fuel processing to steam evaporation.
Area	Southeast Asia (including India and Pakistan).	Southeast Asia (including China, India, and Pakistan).	Areas not covered by GE's patent.

(3) Foreign students in Japan; dispatch of Japanese students abroad

During 1959, 69 persons were sent out for overseas study with the Government's funds or private funds, and 20 persons with the fellowship of the International Atomic Energy Agency. Also, Japan received 16 isotope students, mainly from Southeast Asian countries, under the IAEA's fellowship program. Here is its breakdown:

Government fund and private fund

	Government employee	Atomic Energy Research I	Atomic Fuel Corp.	Private company	Total
Reactor engineering	3	3		30	36
Nuclear fuel retreatment, waste disposal		2	2	6	10
Reactor material	1	1		1	3
Application of radiation ray	6			2	8
Prevention of radiation injury	3	1		2	6
Administration	6				6
Total	19	7	2	41	69

IAEA fellowship

	Government employee	Atomic Energy Research I	Atomic Fuel Corp.	Private company	Total
Reactor engineering		2		4	6
Nuclear fuel retreatment, waste disposal		1	1		2
Reactor material				2	2
Application of radiation ray	1				1
Prevention of radiation injury	1				1
Total	2	3	1	6	12

NOTE.—Not including 8 persons sent from the Education Ministry.

Foreign isotope students received in 1959

Country:	*Number*	Country—Continued	*Number*
Burma	2	Thailand	5
Formosa	5	United Arab Republic	1
Indonesia	2		
Iran	1	Total	16

TABLE 3

This is an itemization of the study on peaceful utilization of atomic energy conducted from fiscal 1954 to fiscal 1959, with chronological review of the progress of the study of each item and related items.

(1) The listing is limited to the research at national testing and research organs covered by the atomic energy budget, the research subsidized with the atomic energy peaceful utilization research fund, and the research conducted on a commission basis with due budget appropriations. The listing skipped the research conducted at the Japan Atomic Energy Research Institute, the Atomic Fuel Corp., and the Radiology Research Institute.

(2) In the table, (*) stands for subsidy and (†) for research on a commission basis (research items without these marks mean research conducted at national testing and research organs).

(3) In the table, (‡) means that research was started in the preceding year as the Government's debt and that cash payment was made in the indicated year.

(4) The amount of appropriations is shown in thousand yen, with fractions cut down.

(5) The name of research was abbreviated as far as possible.

(6) Research item was wrtten briefly in some cases.

(7) Listing was made on an item-by-item basis in principle. Some of the research at national testing and research organs, especially that in the field of utilization of isotopes, however, was listed on an organization-by-organization basis.

1. FUEL AND FUEL ELEMENT

	Appropriations
Investigation for obtaining uranium ore: 1954, Japan mine industry	*243
Prospecting for nuclear fuel resources: 1954, Geology	6,765
Prospecting for uranium resources: 1955, Geology	31,991
Prospecting for uranium resources: 1956, Geology	100,000
Prospecting for nuclear raw material: 1957, Geology	94,500
Survey on nuclear raw material: 1958, Geology	72,895
Survey and research on nuclear raw material: 1959, Geology	54,622
Study of concentration of home-produced uranium ore: 1954, Mitsubishi Metal	*550
Concentration and refining of domestic uranium ore: 1956, Mitsubishi Metal	†28,073
Testing and research on extraction refinery of low purity uranium ore with organic solvent: 1958, Mitsubishi Metal	††40,699
Study of uranium refining by dry method:	
1957 Tokyo Industrial Institute	12,700
1958 Tokyo Industrial Institute	7,500
1959 Tokyo Industrial Institute	2,053
Study of concentration of ore in pegmatite deposit: 1957 Resources Lab.	1,600
Study of utilization of pegmatite ore deposit:	
1958 Resources Laboratory	7,000
1959 Resources Laboratory	8,550
Extraction of uranium from phosphorous ore:	
1954, Nissan Chemical	*3,480
1955, Nissan Chemicali	†15,243
1956, Nissan Chemical	*7,840
1957, Nissan Chemical	††2,390
Study of refining of uranium by solvent extraction from phosphoric acid liquid: Nissan Chemical	*1,782
Study of concentration of uranium ore in sulfurized deposit: 1958, Mining Association	‡5,209
Study of making metallic uranium by reduction of calcium:	
1955, Physics and Chemistry Research Institute	†2,019
1956, Science Research Institute	†8,962
Study of refining uranium: 1955, Electro-Technical Laboratory	5,066
Study of elementary material for reactor: 1956, Electro-Technical Laboratory	11,000
Study of atomic fuel: 1957, Electro-Technical Laboratory	12,350

	Appropriations
Dry-method refining metallic thorium:	
1956, Honjo Zinc	*210
1957, Honjo Zinc	*‡1, 187
Study of making metallic thorium and its alloy: 1958, Metallic Material Laboratory	14, 600
Testing and research on the refining of thorium compounds: 1958, Asahi Electro-Chemical	*5, 839
Study of the method of refining high purity thorium oxide for reactor: 1959, Mitsui, Metal	*‡7, 080
Study of making UO_2–Al system scattered plate reactor fuel element by powder metallurgic method:	
1956, Sumitomo Electric	*6, 370
1957, Sumitomo Electric	*‡1, 085
Study of making UO_2 sinter: 1958, Sumitomo Electric	*7, 864
Study of the method of making uranium oxide nuclear fuel: 1957: Mitsubishi Metal	*11, 212
Study of making uranium oxide fuel units by swaging, etc.: 1959, Mitsubishi Atomic	*‡10, 759
Testing and research on making urania and thoria ceramic fuel: 1958, Toshiba	*5, 668
Testing and research on making ceramic uranium fuel (uranium carbide): 1958, Science Research Institute	*3, 055
Study of canning of atomic fuel:	
1956, Mitachi	*3, 750
1957, Mitachi	*‡5, 730
1958, Mitachi	*‡5, 388, *‡11, 550
Study of melting and ingotmaking of natural uranium:	
1956, Sumitomo Metal	*1, 200
1957, Sumitomo Metal	*‡7, 271
1958, Sumitomo Metal	*‡12, 980
Study of making uranium-chrome alloy fuel rod for Calder Hall type reactor: 1959, Sumitomo Metal	*‡14, 012
Testing and research on the method of making UF_6 and on anticorrosion machines and instruments required in transit in each manufacturing process: 1958, Osaka Metal	*†9, 493
Basic study of various properties of uranium compounds: 1958, Science Research Institute	†6, 677
Study of organic solvent fit for the refining of nuclear fuel material: 1958, Toshiba	*3, 210

2. MODERATOR AND REFLECTOR

Study of manufacturing graphite for reactor: 1954, Japan Chemistry Association	*5, 977
Study of carbon material for reactor:	
1955, Osaka Industrial Laboratory	13, 000
1956, Osaka Industrial Laboratory	15, 000
Study of carbon material: 1957, Osaka Industrial Laboratory	6, 395
Survey of carbon material resources:	
1956, Resources Laboratory	8, 120
1957, Resources Laboratory	10, 000
Survey and study of carbon material resources:	
1958, Resources Laboratory	‡12, 000
1959, Resources Laboratory	3, 500
Study of manufacturing graphite for reactor:	
1955, Showa Denko	†9, 627
1956, Showa Denko	*25, 560
Testing and study on radiation injury of graphite: 1958, Showa Denko	††2, 501
Study of manufacturing graphite for reactor, especially as moderator:	
1956, Tokai Electrode	*9, 750
1957, Tokai Electrode	*‡328
Testing and study on radiation injury of graphite: 1958, Tokai Electrode	††2, 501
Study of manufacturing nonboron petroleum coke: 1956, Coal Laboratory	†1, 248

	Appropriations
Study of aseismatic resistance of graphite for reactor: 1957, Showa Denko	*7, 361
Study of manufacturing heavy water: 1954, Japan Chemistry Association	*108
Trial-manufacture of mass spectrograph: 1954, Kyoto University	*1, 200
Study of measurement of density of heavy water: 1955, Tokayo Metropolitan University	†2, 470
Study of property of liquid hydrogen:	
1954, Tohoku University	*1, 360
1955, Tohoku University	†3, 600
Study of liquidation distilling of hydrogen: 1956, Tohoku University	†7, 743
Testing and study on concentration of deutron by liquidization distilling of hydrogen: 1958, Japan Oxygen	††11, 594
Study of low temperature effects: 1954, Japan Physics and Chemistry	*3, 982
Basic study of exchange reaction: 1954, Showa Denko	*4, 130
Basic study of exchange reaction of heavy water: 1955, Showa Denko	†16, 631
Study of low-density concentration of heavy water by exchange reaction, etc.:	
1956, Showa Denko	*29, 660
1957, Showa Denko	*‡31, 000
Testing and study on concentration of heavy water by dual temperature exchange method: 1958, Showa Denko	††18, 968
Study of concentration of heavy water by dual temperature exchange method: 1958, Showa Denko	†10, 999
Study of manufacturing of heavy water by combination of water distilling methods: 1958, Showa Denko	*‡27, 080
Study of catalyzer for exchange reaction: 1954, Tokyo Industrial Laboratory	*1, 892
Basic study of catalyzer for exchange reaction: 1955, Tokyo Industrial Laboratory	†1, 377
Trial manufacture of heavy water concentration, device and burner for the study of recovery electrolysis method: 1954, Asahi Chemical	*6, 400
Study of high-density concentration of heavy water by recovery electrolysis method:	
1955, Asahi Chemical	†11, 465
1955, 1956, Asahi Chemical	*9, 980
1957, Asahi Chemical	*‡7, 073
Study of heavy water concentration in the final stage: 1958, Asahi Chemical	*‡10, 672

3. MATERIAL FOR REACTOR AND ITS ACCESSORY EQUIPMENT

Study of manufacturing stainless steel material for reactor:	
1956, Sumitomo Metal	*4, 480
1957, Sumitomo Metal	*‡2, 090
Study of testing on the manufacturing and processing of stainless steel tube of reactor: 1958, Sumitomo Metal	*7, 380
Study of stainless steel: 1955, Japan Special Steel Tube	†997
Study of welding, etc., of stainless steel tube for reactor:	
1956, Japan Special Steel Tube	*3, 240
1957, Japan Special Steel Tube	*‡2, 938
Study of making stainless steel tube for reactor by centrifugal casting method: 1959, Japan Metal	*6, 489
Study of property of stainless steel made from pure material: 1957, Metallic Material Laboratory	12, 100
Testing and study on corrosion of metallic material for reactor:	
1957, Metallic Material Laboratory	37, 800
1958, Metallic Material Laboratory	‡28, 730, 64, 940
1959, Metallic Material Laboratory	33, 317
Study of making improved type stainless steel for reactor core: 1958, Japan Metallurgy	*8, 880
Study of making ultra-thin-clad steel for reactor pressure vessel: 1958, Japan Steel	*8, 660
Study of on-the-stop inspection of thick welded structure for reactor: 1958, Toshiba	*2, 405

	Appropriations
Study of separation of zirconium and hafnium: 1956, Nagoya Industrial Laboratory	2,130
Study of separation and refining of zirconium and hafnium: 1958, Nagoya Industrial Laboratory	4,300
Study of melting processing of zirconium alloy for reactor: 1957, Kobe Steel	*9,560
Study of zirconium and its alloy for reactor: 1958, Science Research Institute	*3,225
Study of making metallic natrium for reactor: 1957, Showa Denko	*8,085
Study of removal of internal stress from welded structure of reactor: 1957, Ishikawajima	*7,952
Study of local annealing of welded structure for reactor by high-frequency heating method: 1958, Toshiba	*‡8,228
Study of making boron steel for reactor: 1957, Kawasaki Iron Manufacturing	*3,079
Study of resistance against corrosion of aluminum and its alloy as reactor material: 1956, Science Research Institute	†5,373
Testing and study on aluminum and its alloy for reactor: 1958, Light Metal Association	††9,955
Testing and study on welding process and inspection of aluminum and stainless steel for reactor and its accessory equipment: 1958, Japan Welding Society	††20,667
Study of welding of ultrathick plate and clad steel for reactor: 1958, Japan Welding Society	*9,000
Study of prevention of hot fragility and thermal stress destruction of welded part of stainless steel for reactor: 1958, Metallic Material Laboratory	9,440
Study of welding of reactor material: 1959, Metallic Material Laboratory	17,956
Study of making metallic magnesium: 1958, Furukawa Electric	*6,281
Study of making uranium oxide stainless steel clad fuel element: 1959, Mitsubishi Atomic	*‡3,550
Study of making ceramic material: 1956, Osaka Industrial Laboratory	10,270
Study of ceramic material as reactor structure: 1957, Osaka Industrial Laboratory	11,200
Study of making ceramic material for reactor: 1958, Osaka Industrial Laboratory	8,410
Study of making boron carbide: 1959, Osaka Industrial Laboratory	5,000
Basic study of concentration of isotope by scattering method: 1956, Tokyo Institute of Technology	†2,525
Study for improvement of resistance against heat and corrosion of nonpercolation carbon material in liquid metal: 1957, Japan Carbon	*1,907
Study of spot welding on stainless steel in making reactor container: 1958, Shin Mitsubishi	*‡4,883
Study of processing beryllium and beryllia: 1958, Japan Insulator	*‡9,124
Study of concentration of boron 10: 1956, Science Research Institute	†3,478
Testing and study on concentration of boron 10: 1957, Science Research Institute	†3,609
Study of refining carbon dioxide for reactor: 1959, Showa Carbonic Acid	*‡4,950
Study of vacuum furnace for uranium and its alloy: 1959, Japan Vacuum Technics	*‡11,589

4. REACTOR, REACTOR PARTS, AND ACCESSORY EQUIPMENT

Basic study of reactor design:	
1954, Science Promotion	*1,557
1955, Science Promotion	6,767
Study of boiling phenomenon in tube channel:	
1956, Toshiba	*2,000
1957, Toshiba	*‡5,600
Study of nonsteady boiling heat transmission in tube channel: 1959, Toshiba	*‡3,849
Study of heat exchange in dual cycle system: 1957, Toshiba	*2,585
Study of CO_2 pump, heat exchanger, etc., in CO_2-cooled type reactor: 1958, Fuji Electric	*‡14,616

	Appropriations
Basic study of heat transmission with trial manufacture of liquid metallic circuit:	
1956, Hitachi	*9,900
1957, Hitachi	*‡16,497
Study for development of high-pressure closed motor-driven pump for reactor:	
1956, Mitsubishi Electric	*3,000
1957, Mitsubishi Electric	*‡1,950
Trial-manufacture of large-size canned motor pump for reactor by special processing method: 1959, Mitsubishi Electric	*‡12,853
Basic study of electromagnetic pump with trial-manufacture of small pump: 1957, Hitachi	*5,144
Analysis of strength of pressure vessels for PWR and BWR: 1958, Science Research Institute	*2,769
Study on heat transmission and for prevention of leak in circulation material with trial-manufacture of mockup heat transmission circuit for light water type reactor: 1959, Mitsubishi Atomic	*‡10,526
Trial manufacture of reactor control and measuring device:	
1956, Hitachi	*6,490
1957, Hitachi	*‡5,576
Study of control rod driving device: 1956, Mitsubishi Electric	*3,250
Study of automatic control of reactor: 1955, Electro-Technical Laboratory	6,000
Study of control of atomic powerplant: 1957, Electro-Technical Laboratory	2,700
Basic study for prevention of leak from valve in reactor cooling system: 1957, Okano Valve	*1,370
Trial manufacture of various types of valves required in main piping of power reactor, and study of performance characteristics: 1959, Okano Valve	*‡9,400
Study of direct-viewing type simulator: 1956, Tokyo Meter	*2,440
Study on processing of pressure detection part of reactor: 1958, Tokyo Meter	*1,409

5. PREVENTION OF RADIATION, SHIELD, AND INSTRUMENTS REQUIRED FOR THESE PURPOSES

Study on special cement and concrete for shielding:	
1955, Japan Cement	‡6,718
1956, Japan Cement	*7,160
Study of thermal growth of concrete in power reactor, and countermeasures: 1957, Japan Cement	*1,135
Study on shield material of power reactor and on the method of design and construction: 1958, Architectural Institute	2,680
Experimental study of radiation-proof structure: 1956, Architectural Institute	5,580
Experimental study of shielding, radiation prevention, and radiation-proof structure: 1957, Architectural Institute	9,540
Study on designing and construction of facilities for utilization of radiation rays:	
1958, Architectural Institute	7,216
1959, Architectural Institute	3,426
Study on construction work on concrete for shield against radiation:	
1956, Kajima Construction	*4,440
1957, Kajima Construction	*‡207
Study on protection against scattering gamma ray: 1959 Kajima Construction	*‡4,894
Study on radiation shield material: 1956, Tokyo Industrial Laboratory	2,000
Experimental study on hydrogenated metal as shield material mainly against neutron: 1958, Tokyo University	††4,099
Testing and study on making radiation shield material mainly against neutron: 1958, Science Research Institute	††7,559
Study on paint for shielding against radiation: 1956, Japan Paint	*2,117
Testing and study on paint for weakening the scattered rays of radiation: 1957, Dai Nippon Paint	*698

	Appropriations
Study on glass not colored by radiation ray, and on radiation dosimeter for intense radiation:	
1956, Toshiba	*2, 750
1957, Toshiba	*‡1, 020
Study on glass material for atomic industry: 1958, Osaka Industrial Laboratory	400
Study and manufacture of large-size window glass for shield against radiation: 1958, Japan Optic	*9, 934
Study on organic compound fit for measurement of radiation dosage:	
1956, Science Research Institute	†2, 026
1957, Science Research Institute	†14, 527
Study on chemical measurement of radiation:	
1958, Tokyo Industrial Laboratory	2, 150
1959, Tokyo Industrial Laboratory	3, 860
Trial manufacture of device for disposal of radioactive smog: 1956, Hitachi	*3, 220
Trial manufacture of monitor on contamination of reactor cooling water: 1957, Toshiba	*3, 704
Trial manufacture of device for removal of contamination from radiation waste water and for monitoring: 1957, Horiba Works	*6, 894
Trial manufacture of monitor on radioactive contamination of air: 1957, Kobe Industrial	*3, 501
Study on filtering material used in instruments for prevention of radiation injury: 1956, Tokyo Filter Paper	*2, 370
Trial manufacture of device for removal of contamination of air in facilities utilizing radioactive material: 1957, Toyo Carrier	*3, 159
Study for establishment of method of measuring contamination of air with radioactive material: 1959, Central Measurement Inspecton	16, 200
Trial manufacture of radioactive gas monitor: 1957, Shimazu Works	*3, 104
Trial manufacture of counter type surface contamination meter: 1957, Science Research Institute	*3, 007
Trial manufacture of micro-contamination monitoring device: 1957, Okura Electric	*3, 389
Trial manufacture of low background air monitor: 1958, Hitachi	*2, 901
Study on material for protection against radiation effects: 1956, Science Research Institute	*5, 296
Study on manufacturing and application of fruit sugar solution of germanium used for prevention of, and treatment for, radiation injury: 1957, Coal Laboratory	*1, 173
Study on material for protection against radiation effects: 1958, Science Research Institute	†‡7, 067
Testing and study on film badge for gamma ray: 1955, Fuji Film	†1, 844
Testing and study on film badge for neutron:	
1956, Fuji Film	*5, 070
1957, Fuji Film	*‡2, 786
Study for improvement of film badges for gamma ray and neutron: 1958, Fuji Film	*3, 683
Trial manufacture of radioactive material handling device:	
1954, Radioisotope Association	*3, 074
1955, Radioisotope Association	†3, 200–
Study on electric remote control device:	
1956, Toshiba	*100
1957, Toshiba	*‡2, 891
Trial manufacture of periscope:	
1956, Shimazu Works	*700
1957, Shimazu Works	*‡1, 634
Trial manufacture of fuel destruction detecting device applying Cerenkov effect: 1958, Hitachi	*5, 982
Study on prevention of danger and on radioactive waste: 1954, Science Promotion	*202
Study on disposal of radioactive waste:	
1955, Tokyo University	†865
1956, Tokyo University	†1, 220
Study on disposal of radioactive waste gas:	
1955, Tokyo University	†937
1956, Tokyo University	†1, 446

	Appropriations
Study on disposal of radioactive waste slurry:	
1955, Kyoto University	†622
1956, Kyoto University	†1, 230
Study on mutural separation of uranium nuclear fission product and plutonium:	
1955, Tokyo University	†1, 772
1956, Tokyo University	†2, 801
Study on disposal of radioactive waste liquid:	
1955, Tokyo Industrial Laboratory	2, 400
1955, Nagoya Industrial Laboratory	1, 000
1956, Nagoya Industrial Laboratory	12, 570
1957, Nagoya Industrial Laboratory	3, 600
Study of countermeasures against radioactive matters in the air: 1959, Labor Sanitation Institute	5, 200

6. MEASURING INSTRUMENTS AND OTHER MACHINES AND INSTRUMENTS

Establishment of radiation standard and correction of meter: 1954, Electro-Technical Laboratory	11, 529
Study on radiation measurement: 1955, Electro-Technical Laboratory	23, 500
Establishment of radiation standard and correction of meter: 1956, Electro-Technical Laboratory	30, 400
Study on establishment of radiation standard and on regulation: 1957, Electro-Technical Laboratory	86, 000
Study on establishment of radiation (radioactivity) standard:	
1958, Electro-Technical Laboratory	40, 908
1959, Electro-Technical Laboratory	54, 700
Study on measurement of neutron ray: 1955, Electro-Technical Laboratory	13, 492
Testing and study on prevention of radiation injury to radiation measuring instrument parts (insulating material, electronic tube, etc.): 1958, Toshiba	††7, 436
Testing and study on prevention of radiation injury to radiation measuring instrument parts (resistor, semiconductor, etc.): 1958, Science, Research Institute	††6, 161
Study on radiation measuring instruments: 1954, Science Promotion	*90
Trial manufacture of inner diaphragm type high resistance: 1955, Fuji Communication Apparatus	†1, 838
Trial manufacture of mold type high resistance: 1955, Toshiba	†1, 107
Trial manufacture of small-sized potentionimeter vacuum tube: 1955, Toshiba	†1, 364
Trial manufacture of photoelectron amplifying tube: 1955, Toshiba	†5, 281
Trial manufacture of box-type photoelectron amplifying tube: 1956, Toshiba	*2, 570
Trial manufacture of low-noise photoelectron amplifying tube: 1956, Hamamatsu TV	*3, 820
Trial manufacture of scintillator for gamma ray: 1955, Hamamatsu TV	†1, 780
Study on amplifying apparatus applying electroluminescence: 1958, Kobe Industrial	*2, 560
Trial manufacture of scintillator (sodium iodide) for gamma ray: 1955, Kobe Industrial	†2, 011
Trial manufacture of scintillator for gamma ray: 1956, Kobe Industrial	*4, 310
Trial manufacture of scintillator for fast neutron: 1955, Toshiba	†1, 666
Trial manufacture of scintillator for low energy neutron: 1956, Toshiba	*1, 570
Trial manufacture of scintillation counter: 1955, Shimazu Works	†4, 365
Study on trial manufacture of magnetoelectron tube type counter tube for radiation measurement: 1956, Toshiba	*1, 180
Trial manufacture of counter type neutron measuring device:	
1955, Hitachi	†2, 165
1955, Science Research Institute	†3, 668
Trial manufacture of portable ion chamber type neutron meter: 1956, Science Electric	*950
Trial manufacture of ionization chamber type radiation measuring device:	
1955, Kobe Industrial	†5, 742
1956, Kobe Industrial	*5, 680

	Appropriations
Trial manufacture of boron-coated type dosimeter for neutron: 1955, Science Research Institute	†514
Trial manufacture of portable ion chamber type neutrol meter: 1956, Science Research Institute	*2, 910
Study on ion chamber type integral dosimeter for control: 1956, Horiba Works	*2, 040
Trial manufacture of ultramulticrest analyzer:	
1956, Toshiba	*1, 860
1957, Toshiba	*‡3, 962
Study of universal type radiation spectrometer:	
1956, Shimazu Works	*2, 030
1957, Shimazu Works	*‡921
Testing and study on mass analysis for measurement of uranium existence ratio: 1958, Hitachi	††10, 839
Trial manufacture of interference spectrometer for the analysis of radioisotopes: 1959, Osaka Industrial Lab	9, 710
Trial manufacture of electron linear accelerator:	
1956, Toshiba	*3, 740
1957, Toshiba	*‡2, 352

7. ATOMIC SHIP

Study on atomic ship:	
1957, Transportation Technics Council	7, 000
1958, Transportation Technics Council	‡5, 000
Study on hull of atomic ship: 1959, Transportation Technics Council	6, 450
Study on rolling and vibration of atomic engine:	
1958, Transportation Technics Council	38, 020
1959, Transportation Technics Council	14, 936
Study on shielding for atomic ship: 1959, Transportation Technics Council	6, 000
Experimental study on control of marine reactor: 1958, Kawasaki Heavy Industry	*‡15, 360
Experimental study on the dropping of control rod due to the rolling of marine reactor: 1958, Kawasaki Heavy Industry	*2, 028
Study on position of reactor and neighboring construction in atomic ship: 1958, Mitsubishi Nihon Heavy Industry	*8, 316

8. NUCLEAR FUSION

Study on ultrahigh temperature plasma and nuclear fusion: 1958, Electro-Technical Laboratory	20, 000
Study of induction pinch type plasma: 1958, Toshiba	†2, 997
Trial manufacture of low inductance condenser for generation of ultrahigh temperature plasma: 1958, Kansai Futai	†2, 395
Study on creation of nuclear fusion high temperature plasma and on its observation: 1958, Kobe Industrial	†8, 528
Study on creation of nuclear fusion ultrahigh temperature plasma and on its observation: 1958, Kobe Industrial	*1, 905
Study on ultrahigh temperature plasma for nuclear fusion: 1958, Mitsubishi Atomic	†7, 478
Study on ultrahigh temperature plasma produced by intense current ring discharge: 1958, Toshiba	†6, 996
Study on measurement of ultrahigh temperature plasma phenomena: 1958, Science Research Institute	†2, 976

9. UTILIZATION OF RADIOISOTOPE

Study on preparation of label compound: 1957, First Chemical	*4, 646
Study on promotion of polymerization and condensation of natural gas and acetylene by exposure to radiation: 1958, Science Research Institute	†6, 764
Study on manufacturing of radioactive drugs: 1957, Dai Nihon Pharmaceutical	*3, 428
Study on graft polymerization of vinyl high polymer by exposure to radiation: 1958, Science Research Institute	†5, 008
Study on breeding of special plants in cold area: 1957, Toyana Prefectural Agricultural Experimental Station	*3, 855

	Appropriations
Study of improvement of principal garden plants: 1957, Tokyo College of Agriculture	*1,026
Study on measurement of curie value of large-quantity cobalt 60: 1958 Science Research Institute	††9,025
Radiation study of genetics:	
1957, Institute of Genetics	11,871
1958, Institute of Genetics	7,685
1958, Institute of Genetics	‡3,600
1959, Institute of Genetics	9,535
Study of mechanism of contamination of water, air and food, and study of poison neutralization mechanism:	
1956, Public Sanitation Bureau	1,577
1957, Public Sanitation Bureau	7,082
1958, Public Sanitation Bureau	7,363
1958, Public Sanitation Bureau	*6,410
1959, Public Sanitation Bureau	7,038
Qualitative change in food due to nutrition metabolism and radiation, and its biological effects:	
1957, Nutrition Council	1,062
1958, Nutrition Council	5,205
1959, Nutrition Council	3,811
Study on radiation effects on immunity and physical factor, and study on antibiotics:	
1956, Prevention Sanitation Council	4,143
1957, Prevention Sanitation Council	2,000
1958, Prevention Sanitation Council	8,234
1959, Prevention Sanitation Council	21,083
Study of standardized testing method for radioactive drugs and of radiation sterilization of medical supply:	
1956 Hygienic Laboratory	4,040
1957, Hygienic Laboratory	738
1958, Hygienic Laboratory	7,908
1959, Hygienic Laboratory	10,656
Study on route of leprosy germ:	
1957, Institute of Leprosy	1,520
1958, Institute of Leprosy	7,592
Do	*4,240
1959, Institute of Leprosy	5,646
Study on radiation treatment for malignant tumor in chest organ:	
1956, Tokyo First Hospital	2,303
1957, Tokyo First Hospital	2,558
1958, Tokyo First Hospital	4,898
Do	*2,448
Study on radiation treatment for malignant tumor in digestive organ:	
1956, Tokyo Second Hospital	2,262
1957, Tokyo Second Hospital	6,500
1958, Tokyo Second Hospital	2,000
Study on treatment for malignant tumor in gynecology:	
1957, Osaka Hospital	1,720
1958, Osaka Hospital	6,280
Do	*6,280
Study of internal distribution of TB medicine and appropriate dosage: 1959, Kiyose Hospital	1,922
Study of microstructure and function of TB bacilli: 1959, Toneyama Hospital	5,775
Study on improvement of fertilization, improvement of breeding: measurement of irrigation flow, and improvement of method of raising livestock:	
1956, Agricultural Technic Institute	12,660
1957, Agricultural Technic Institute	36,660
1958, Agricultural Technic Institute	37,499
Do	*31,407
Study for improvement of soil and improvement of fertilization on volcanic ash field: 1959, Tohoku Agricultural Experiment Station	7,850

	Appropriations
Study for improvement of fertilization on peat bog, and study on disease of potato:	
1956, Kanto Higashiyama Experiment Station	5,980
1957, Kanto Higashiyama Experiment Station	7,479
1958, Kanto Higashiyama Experiment Station	9,985
Do	*3,098
1959, Kanto Higashiyama Experiment Station	1,267
Study for improvement of soil of "akiochi" (decline in autumn) paddy field:	
1957, Tokai Kinki Experiment Station	5,021
1958, Tokai Kinki Experiment Station	4,230
Do	*3,432
1959, Tokai Kinki Experiment Station	10,741
Study for improvement of sterile soil in warm area, and on damage to crops by blight and noxious insects:	
1957, Kyushu Experiment Station	1,435
1958, Kyushu Experiment Station	6,095
Do	*3,400
1959, Kyushu Experiment Station	546
Study on chickens leukemia and on virus proliferation:	
1956, Live Stock Hygene Experiment Station	750
1957, Live Stock Hygene Experiment Station	11,841
1958, Live Stock Hygene Experiment Station	11,968
Do	*1,640
1959, Live Stock Hygene Experiment Station	1,421
Study on biopolymerization of silk yarn albumin and on improvement of breeding of mulberry and silkworm by exposure to radiation:	
1956, Sericulture Experiment Station	7,190
1957, Sericulture Experiment Station	3,578
1958, Sericulture Experiment Station	5,107
1959, Sericulture Experiment Station	3,854
Study on insecticide and mold prevention, and on preservation of food by gamma ray irradition:	
1956, Food Research Institute	280
1957, Food Research Institute	4,195
1958, Food Research Institute	5,462
Do	*4,240
1959, Food Research Institute	484
Study on qualitative improvement of timber, fertilization for timber, and quality control:	
1956, Forestry Experiment Station	9,030
1957, Forestry Experiment Station	7,571
1958, Forestry Experiment Station	14,753
Do	*8,500
1959, Forestry Experiment Station	8,464
Study for improvement of fish breeding feed, nutrition value of marine animal oil, and preservation and processing of marine food by gamma irradiation:	
1956, Tokai Fisheries Research Institute	14,739
1957, Tokai Fisheries Research Institute	8,120
1958, Tokai Fisheries Research Institute	6,428
1959, Tokai Fisheries Research Institute	1,975
Study on breeding by outdoor irradiation of radiation rays:	
1956, Agricultural and Fisheries Technological Council	1,991
1959, Agricultural and Fisheries Technological Council	46,530
Study on abrasion of machine tools:	
1958, Mechanical Laboratory	10,040
1959, Mechanical Laboratory	1,116
Study of analysis method applying radiation:	
1959, Tokyo Industrial Laboratory	11,887

	Appropriations
Study of application of radiation to analytical chemistry and to chemical industry:	
1956, Tokyo Industrial Laboratory	13,000
1957, Tokyo Industrial Laboratory	18,400
1958, Tokyo Industrial Laboratory	15,544
1959, Tokyo Industrial Laboratory	5,029
Study on the method of refining and testing reagent:	
1958, Osaka Industrial Laboratory	8,952
1959, Osaka Industrial Laboratory	3,572
Study of high polymer chemistry, etc., by radiation ray:	
1956, Nagoya Industrial Laboratory	5,000
1957, Nagoya Industrial Laboratory	43,567
1958, Nagoya Industrial Laboratory	131,604
Do	*71,600
1959, Nagoya Industrial Laboratory	30,471
Study of metabolism-in-vitro of fermentation germs, and on mutation of micro-organism due to exposure to radiation:	
1956, Fermentation Laboratory	2,000
1957, Fermentation Laboratory	8,075
1958, Fermentation Laboratory	6,834
Do	*4,710
1959, Fermentation Laboratory	2,929
Study for improvement of dyeing and hygroscopy of textiles by exposure to radiation:	
1957, Textile Industry Council	7,400
1958, Textile Industry Council	850
1959, Textile Industry Council	6,280
Trial manufacture of high sensibility dosimeter using radiation-sensible glass: 1959, Electro-Technical Laboratory	3,395
Study on measurement of thin film:	
1957, Industrial Arts Institute	2,710
1958, Industrial Arts Institute	1,580
1959, Industrial Arts Institute	1,185
Study of application of isotope to mining industry:	
1957, Resources Laboratory	8,400
1958, Resources Laboratory	1,433
1959, Resources Laboratory	2,992
Study of construction method against drift sand:	
1957, Transportation Technics Research Council	8,604
1958, Transportation Technics Research Council	10,795
Do	*6,010
1959, Transportation Technics Research Council	1,143
Study on construction from hydraulic engineering viewpoint, and on neutralization of reinforced concrete:	
1956, Public Works Research Institute	4,220
1957, Public Works Research Institute	5,970
1958, Public Works Research Institute	6,178
Do	*3,530
1959, Public Works Research Institute	5,042

ATOMIC POWER GENERATION PROGRAMME (SUMMARY)

(By the Ministry of International Trade and Industry, Japan)

JULY 28, 1960.

1. OUTLINE

(1) The term taken in this programme is twenty years as from 1961 which is divided into two parts before and after a time when atomic power becomes competitive in generating with thermal power, especially fuel oil. The former period is considered as a preparatory or semi-commercial stage and the latter as a commercial stage. And the competitive time is estimated to be approximately 1970.

(2) During the latter ten years, the generation of approximately 7,500–6,000 MWE is expected to be developed by nuclear power.

(3) During the former period, it is estimated that nuclear power stations will be built up to the capacity of about 1,000 MWE in total.

2. DEMAND AND SUPPLY OF ELECTRICITY

(*1*) *Demand*

(*a*) Assumptions:

Rate of economic growth as a whole (per year):	Percent
Former period	7
Latter period	5
Rate of increase in industrial production index:	
Former period	9.5
Latter period	5.8

Assuming these, the demand for energy in total will be 2.4 times in 1970 and 3.8 times in 190 respectively as much as that in the base year (average during three years from 1956 to 1958).

(*b*) Of total energy the demand for electricity will increase gradually up to 44.9 per cent in 1970 and 48.5 per cent in 1980, compared with 36.2 per cent in the base year. (See Chart 1.)

(*2*) *Supply*

(*a*) *Hydraulic power.*—Potential hydro-power is 35,370 MWE at maximum capacity, and hydro-electricity potential per year is 130,000 million KWh in Japan. Of these potentials 6,000 MWE will be developed from 1964 to 1970, 8,000 MWE from 1971 to 1980.

(*b*) *Thermal power.*—An increase in hydraulic power is limited, so that the rest will have to be supplied by thermal power in order to meet the huge demand for electricity in the future. Figures are shown in the chart 1.

Thus it is quite clear that the main supplying source of electricity will be thermal power at base load while hydro-power being at peak-load.

3. ATOMIC POWER GENERATION

Target figures of nuclear power to be developed in the future are based upon the following methods

First: Forcasting of the time when nuclear power becomes fully competitive with thermal power (hereinafter cited as "economical point")

Second: Forecasting of the total capacity of nuclear power generation during the periods after the economical point, in view of the system of supplying electricity from different kinds of sources, the amount and way to provide funds needed, and an influence upon the international balance of payment.

Third: Forecasting of the total capacity of nuclear power generating during the period before the economical point, in view of a necessity to make preparations for the development for the future.

(*1*) *Economy of nuclear power*

One of most important factors in forseeing on the nuclear power generation in the future is a trend of its economy. Several assumptions that have been set in the series of discussions are as follows.

(*a*) Comparison in generating costs is made between nuclear power and the thermal power represented by oil.

In Japan, oil is considered to be the cheapest of conventional energy in generating even in the future.

(*b*) Each generating cost is average cost during the whole depreciation period (about twenty years).

(*c*) Estimation of nuclear power costs is based upon the date on Pittman report (AEC, U.S.A.) and Hinton report (U.K.).

(*d*) Oil prices, capacity factors (load factors) interest rates, which we are not able to estimate precisely, have made future cost tendency a band curve.

On these assumptions, the estimation of future costs of both powers, as shown in Chart 2, has made it clear that nuclear power would become competitive with thermal power approximately in 1970 at a level of 6.67 to 8.34 mills per kilowatt hour.

(*2*) *Capacity of nuclear power stations during period after the economical point (1970–1980)*

The following considerations have been taken in estimating the total capacity during the period.

First: Technical and economic status in optimising the combination of different power sources in generation of electricity.

Second: Volumes and means of finance for the development of the generation, and influence upon the international balance of payment.

Third: Manufacturing ability and capacity in the future.

Fourth: Selection of sites of the nuclear power stations.

Fifth: Stability in securing the energy sources.

On these assumptions it is concluded that about 30 percent of the total generation capacity, excluding hydro-power generation, to be developed to meet an increased demand for electricity during periods after the economical point is an optimal size of nuclear power generation; that is, 7,500–6,000 MWE.

(*3*) *Capacity of nuclear power stations during the period before the economical point (1961–1970)*

Although it is a preparatory, tentative or semi-commercial Stage in the development of nuclear power, this period is so important that it would have a decisive influence upon the targets of nuclear power development in the ensuing commercial period.

In this stage, approximately 1,000 MWE will be necessary to develop.

(*a*) In order to build nuclear power stations of 7,500–6,000 MWE during the commercial period with considerable amount of national manufacturing technology, it is necessary to have built several stations by 1970 for the purpose of establishing the manufacturing technics with reactors, related apparatus, various materials and nuclear fuels on the part of Japanese manufacturers.

(*b*) On the part of power business, some preparatory experiences are required in order to become familiar with the building and operating technics of nuclear stations.

4. PROBLEMS CALLING FOR MORE DELIBERATIONS

It is now evident that nuclear power generation will play a very important role in securing energy sources in the future. In the course of realizing the targets of this programme, there are several problems to be solved.

(*a*) *Year-by-year project of development.*—This Programme contains only targets of the development of nuclear power in 1970 and 1980. To achieve these targets, it is desired to make up more concrete blue prints on year-by-year scale.

(*b*) *Types and unit size of reactors.*—It is necessary to give a technical and economic appreciation to particular types, unit capacity and adaptability to conditions in Japan, upon which economics of nuclear power would mainly depend.

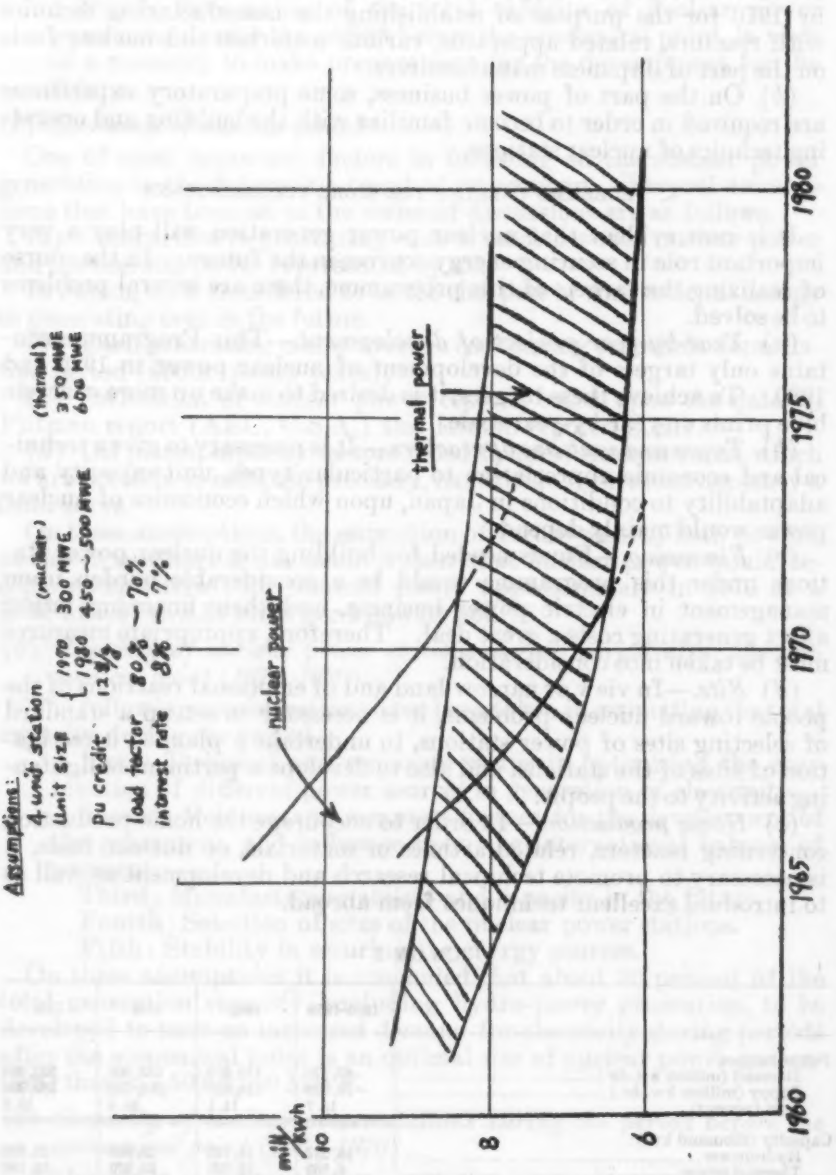
(*c*) *Financing.*—Funds needed for building the nuclear power stations under this programme would be a considerable burden upon management in electric power business, and their financing might affect generating costs a great deal. Therefore, appropriate measures must be taken into consideration.

(*d*) *Site.*—In view of narrow land and of emotional reactions of the people toward nuclear problems, it is necessary to set up a standard of selecting sites of power stations, to undertake a planned investigation of sites of the stations, and also to develope a pertinent enlightening activity to the people.

(*e*) *Home production.*—In order to encourage the home production concerning reactors, related articles or materials, or nuclear fuels, it is necessary to promote technical research and development as well as to introduce excellent techniques from abroad.

CHART 1

	1956–1958	1963	1970	1980
Power balance:				
Demand (million kw.-hr.)	67,170	110,919	193,500	332,000
Suppy (million kw.-hr.)	77,926	124,826	216,730	369,300
Loss (percent)	13.7	11.1	10.6	10.0
Capacity (thousand kw.):				
Hydropower	10,247	14,792	20,800	28,800
Thermal power	6,560	13,020	29,670	58,140
Total	16,807	27,812	50,470	86,940


Assumptions:
4 unit station
Unit size { 1970 300 MWE
1980 450 ~ 500 MWE
Pu credit 12½
load factor 80% ~ 70%
interest rate 8% ~ 7%
(nuclear)
(thermal)
350 MWE
600 MWE
nuclear power
thermal power
mill/kwh
10
8
6
1960
1965
1970
1975
1980

TEXT OF REPLY FROM ATOMIC ENERGY COMMISSION, GOVERNMENT OF INDIA

Please refer to your letter of March 4, 1960. Our reply is attached. We may add some supplementary information at a later date.

* * * * * * *

The Planning Commission and the Government of India took a firm decision in 1959 to establish a nuclear power station of 250 MW capacity in the Bombay-Ahmedabad region. In order to fit this station better into the local grid, it has been decided that it should now consist of two units of 150 MW(e) each, with a total capacity of 300 MW. The Atomic Energy Commission have also proposed an additional 300 MW of nuclear power based on natural uranium reactors to be installed during the period of the Third Five Year Plan. One of these units of 150 MW has been proposed for the Delhi-Punjab grid to be in operation by March 1966, while the location of the other, also of 150 MW has not yet been settled.

The economics of these nuclear power stations based on the data of graphite moderated gas cooled reactors being built in the UK are given in Annexures I and II.

It has also been proposed that 100 MW of nuclear power be installed in atomic power stations using enriched uranium as fuel. One of the stations will be of 75 MW(e) capacity to be located in the Delhi-Punjab area, and to be commissioned by mid-1964, and the second, a small station of about 25 MW(s), probably in the Rajasthan area. The present thinking is that the 75 MW station could be of the pressurised water type, but with new developments incorporated, and the 25 MW station of the organic moderated type. The costs of these, as discussed recently with the representatives of the US AEC, are given in Annexures III and IV.

The Indian atomic energy programme will have to be ultimately based on the use of thorium, as India's thorium reserves amounting to half a million tons of thorium in monazite ore containing 9% and above of ThO_2 are of the same order of magnitude as the total world reserves of uranium. Such a programme will, therefore, consist of a first stage of reactors based on natural uranium, which will produce plutonium for the subsequent stages. There is no firm decision regarding the subsequent stages yet, as this must inevitably depend on technical developments during the next ten years. The plutonium produced in the first stage will either be used in fast breeder reactors in the second stage to produce more plutonium for the third stage, or it will be used in reactors with a thorium blanket to produce U_{233}. The third stage will then consist of reactors which may be started off with plutonium or U_{233} as fissile material, but which will be fed for the rest of their life on thorium.

As it is expected that at the present rate of increase the installed capacity will reach a figure of 50 million kilowatts between 1975 and 1980, most of the conventional sources of power will have been tapped by then, and future expansion will have to depend on nuclear power. A substantial nuclear power programme starting from now has, therefore, to be built up during the next 15 years, in order to be able to meet this future demand. The first stage power programme has therefore to be embarked on immediately in any case, and if the future should show that the present figures regarding breeding were too optimistic, the first stage programme will have to be stepped up further.

ANNEXURE - I

Cost of Nuclear Power (natural uranium)

(win reactor station 300 MW (150 x 2)

Assumptions

Capital cost (1)	Rs 1700/kwe s.o.
Cost of fabricated fuel (2)	Rs 3 lakhs/tonne
Overall efficiency	28%
Fuel irradiation	3000 MWD/tonne
Fuel inventory (3)	1.15 tonne/MWe s.o.
Operation and maintenance charges	0.18 nP/kwh
Load factor	80%
Life of plant	20 years

Power costs	nP/kwh
Interest at 4.5% and (4)	
Depreciation at 3.19% (5)	1.87
Operation and maintenance	0.18
Fuel inventory charges at 4.5%	0.22
Fixed charges	2.27
Fuelling charges incl. credit for Pu	1.16
Total	3.43

Notes: (1) Latest information shows that the capital cost of a large size nuclear power station based on natural uranium, in India will not exceed £120/kw.s.o. (or Rs 1600/-). As the stations will be of two reactors each, a higher figure of Rs 1700/kw, the older figure, has been used.

(2) The cost of fabricated fuel in the U.K. now is approximately Rs 2.6 lakhs/tonne. It can be expected that fuel elements in India should, on the basis of available grade of ore, be available at Rs 3 lakhs/tonne They may well be available cheaper, as the grade of Indian ore is improving as drilling and mining proceed.

(3)

Annexure I

(3) The fuel inventory in the modern Japanese 150 MW station is estimated at 1.15 tonne/MWe (hollow tubes) and in Trawsfynydd (two reactors, each of 250 MW) station at 1.14 tonnes/MWe (solid rods).

(4) The interest charges are those current in India today. 11 State Governments raised loans in 1958, totalling some Rs 50 crores at 4-1/4%, and the Central Government raised the loans given below, totalling Rs 165 crores at the interest rates shown.

3-1/2% Bonds 1963 3-3/4% National Plan Bonds Fifth Series (3-3/4% 1968) 4% Loan 1973	135 crores
3-1/2% Loan 1968 (Special Creation	30 crores

As far as interest rates on internal loans are concerned, therefore, the 4-1/2% assumed in the calculations of the Atomic Energy Commission is fully justified.

(5) The Central Water and Power Commission charges depreciation at 2.401% as an average of different depreciation rates on different parts of the plant. This corresponds on a sinking fund basis to an average life of 25 years. For a nuclear power station, a higher rate of 3.19% has been assumed, corresponding to an average life on a sinking fuhd basis of 20 years. Parts of the power station may have a shorter life, but other parts of the power station will have a longer life. In a graphite moderated gas cooled power station, the cost of the reactor is under 40% of the total cost of the power station.

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ANNEXURE - II

Cost of Thermal Power (coal fired)

Assumptions

Capital cost (6)	Rs 850/kwe s.o. Rs 1050/kwe s.o.
Station consumption	6%
overall efficiency (7)	29.6%
Load factor	80%

Power costs nP/kwh

Interest at 4.5% and Depreciation at 2.401%	0.84	1.04
Operation and maintenance	0.18	0.18
Fixed charges	1.02	1.22
Fuelling charges (8)		
Coal (9000 BTU/lb)		
at Rs 35/ton	2.01	
Rs 37 1/2 ton	2.15	
Rs 40/ton	2.29	
Rs 42 1/2/ton	2.43	
Rs 45/ton	2.58	
Total for coal		
at Rs 35/ton	3.03	3.23
Rs 37 1/2/ton	3.17	3.37
Rs 40/ton	3.31	3.51
Rs 42 1/2/ton	3.45	3.65
Rs 45/ton	3.60	3.80

Notes: (6) The capital cost usually adopted for thermal (coal) stations is Rs 800/kw and if 6% station consumption is allowed for, it works out to Rs 850/kw s.o. If modern technique is provided for, and if charges for such items as cooling water, coal stacking yards etc. are fully included, the cost per kw s.o. would be much higher and may exceed Rs 1050/kw, the capital charge of the third Tata-Trombay set. The cost of the latest Chandrapura power station of the

Damodar Valley Corporation with a unit size of 125 MW, which has just been completed, works out at Rs 1171 per kilowatt.

(7) The overall efficiency of 29.6% can be achieved by incorporating certain technological improvements involving higher capital cost.

(8) The fuelling charges would depend upon the cost of coal. Five specific values have been shown in the table. Reference is invited to figure 1 which gives the generating cost of modern coal burning stations for varying values of coal costs. For a coal price of Rs 38.5/ton, nuclear power costs come equal to thermal power costs if the capital cost of the termal station is taken at Rs 1050/kw s.o., If, however, the capital cost is taken at Rs 850/kw s.o., the corresponding cost of coal to equate the two costs of power works out to Rs 42/ton.

The present price of 9000 BTU/lb coal in the Delhi-Punjab region is estimated to be about Rs 37 1/2 ton and in Madras region about Rs 42 1/2 ton.

ANNEXURE - III

	Conventional India Mills/KWH	BWR India mills/KWH
Fixed Charges		
Operating Costs	2.0	4.25
1. Fuel Cost	6.1	4.17
2. Operation and Maint.	.5	.50
3. Nuclear Insurance	---	----
	8.6	8.92
(1) Capital Cost	$200/KW	$385/KW
Load Factor	80%	80%
(2) Fixed Charges	6.9%	7.7%
(3) Thermal Efficiency	25%	31%
(4) Coal - $9/ton (10,000 BTU)		
	45 ¢/10^6 BTU	

ANNEXURE IV

ESTIMATED CAPITAL COST 75 MWE PWR & CMR REACTORS

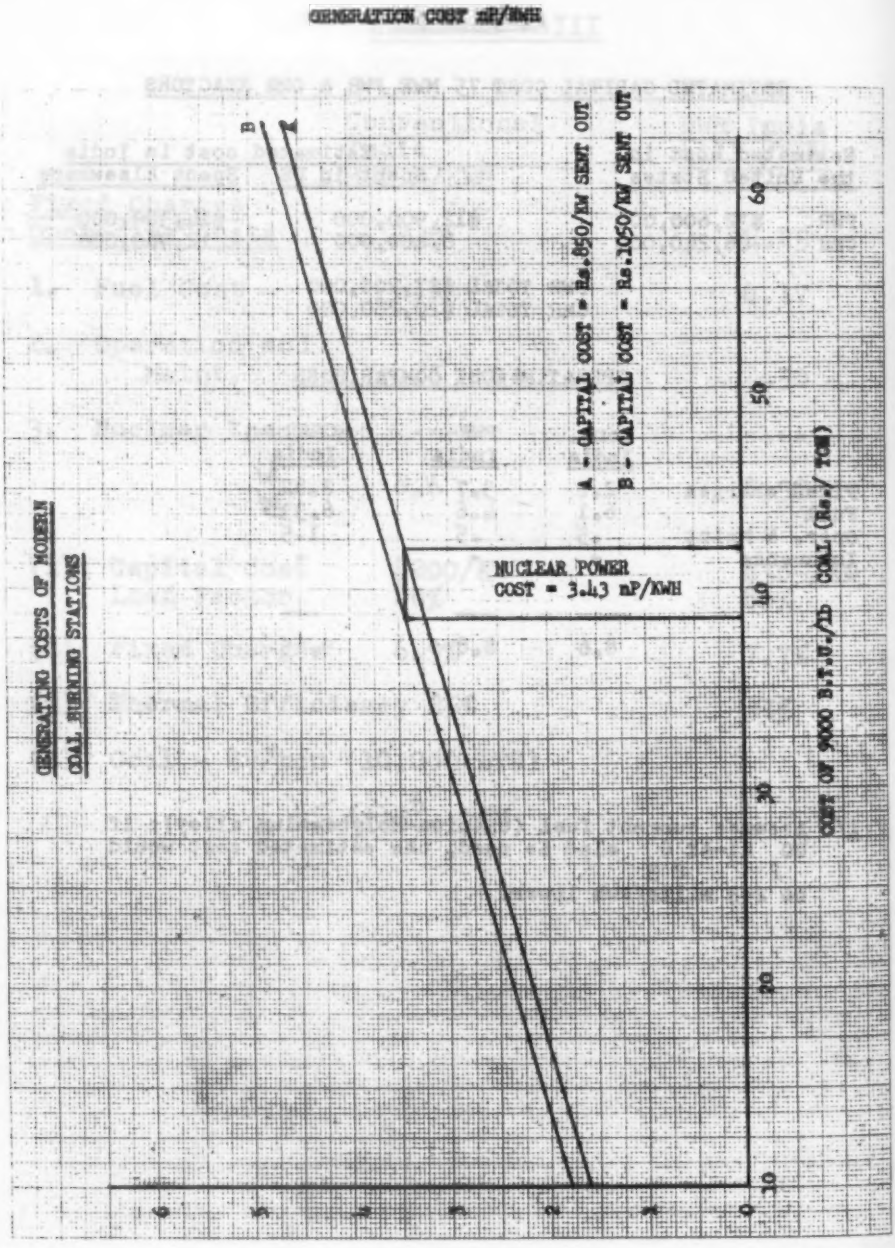
	Estimated cost in the United States	Estimated cost in India	
		Spent in US	Spent Elsewhere
PWR	$32,600,000	$12,900,000	$14,300,000
CMR	26,240,000	8,400,000	12,080,000

PWR TOTAL $27,200,000
CMR TOTAL $20,280,000

OPERATING COST COMPARISONS

	Conv. India	PWR India	CMR India
Fixed charges	2.0	3.7	2.82 1/
Fuel	6.1	4.6	6.33 1/
Oper. & Maint	.5	.5	1.5
Insurance	-	-	-
	8.6	8.8	9.65

1/ Assumes current fuel (Uranium-Molybdenium alloy); if UO_2 Al-Al_2O_3 clad is used, the estimated cost would be 2-3 mills/kwh lower.


GENERATION COST nP/KWH
GENERATING COSTS OF MODERN
COAL BURNING STATIONS
A - CAPITAL COST = Rs.850/KW SENT OUT
B - CAPITAL COST = Rs.1050/KW SENT OUT
NUCLEAR POWER
COST = 3.43 nP/KWH
COST OF 9000 B.T.U./LB COAL (Rs./TON)
B
A
0
1
2
3
4
5
6
10
20
30
40
50
60

STAFF NOTE.—During Review Staff visits to Europe on fact-finding missions, a request was made to the Istituto di Economia delle Fonti di Energia, Bocconi University, Milan, for a study on Italian nuclear power outlook. Pertinent correspondence and the report appear below.

LETTER FROM ISTITUTO DI ECONOMIA DELLE FONTI DI ENERGIA TO REVIEW STAFF

I believe that by the time you will get this letter you have received the study on "Electric Development in Italy and Nuclear Power Utilization Outlooks in the Next Ten Years."

Unfortunately for the lack of time the translation has been done in hurry and we did not find the time for a deep control of it. Therefore we authorize you, before printing, to make any change you believe necessary in the language.

* * * * * * *

ELECTRIC DEVELOPMENT IN ITALY AND NUCLEAR POWER UTILIZATION OUTLOOKS IN THE NEXT TEN YEARS

I - DEVELOPMENT AT 1959

1) At the beginning of 1960 it is interesting to make a survey of the situation of electric power supply in Italy and its outlooks in the future. 1960 is in fact the year appointed to see the completion of the building program scheduled by the power companies in 1956. Moreover, an investigation of this kind is particularly useful, so much the more if we consider that requirements of electric power grew very substantially also in the period following that of post-war recovery with the exception of a short period related to the general economical recession. Such trends, joint to the fact that the general economic cycle is likely to point decidedly towards expansion, thus entailing the requirements of electric power to maitain a high level, give rise to the problem of meeting the future needs of said power source, with special concern to the investments required by new plants and facilities.

2) According to the first temporary statistical data, electric power in Italy attained, in 1959, about $48.9 \cdot 10^9$ kWh($38.6\ 10^9$ of which, i.e. 79%, hydroelectrical and $10.3 \cdot 10^9$, i.e. 21%, thermoelectrical, geothermical included), racking up a 7.46% increase over the $45.5 \cdot 10^9$ kWh totally produced on 1958. It appears to be the highest increase range amongst those scheduled over the last four years[1]. The

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1) It is interesting to stress that the yearly increase rates were 8.5% during 1920-1930; 6.2% over the period 1930-1940, that was directly influenced by the world crisis, and about 7% from 1947.to 1959. In other words,

actual user's needs exceeded, however, those shown by the generation data, as a slight activ balance was realized on exchange with foreign countries. Consequently the needs in 1959 were about 7.6% more than in 1958[1]. So far it is not possible to state what classes of users were contributing to a greater extent to the overmentioned rise, but we are not far from the truth believing that a general trend is involved.

The generation progress of the Italian electrical plants is shown on table I. ..

If we consider the "10-years development plan" (Vanoni plan), we see that over the period 1955-1959 the electric power needs, with concern to generation scheduled a total boost of 37.5% i.e. more than 7% per annum, that is to say a range that is clearly higher than that forecasted by the "Schedule" covering the yearly output capacity of plants.

3) The Italian users's electrical power needs have been entirely covered, also over the later period, thanks to facilities meeting all generation, transport and distribution requirements. Since the end of the second world war, the building program progressed incessantly : besides proportioneting the facilities to the steady rise

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with exception of the years of the second World War, the increase rate is not far from having been doubled in ten years (7.2%).

1) The generation progress in the electricity field is evidenced by the comparison with the foregoing years: with 1938 showing a generation schedule of $15.5 \cdot 10^9$ kwh; with 1941 when $20.8 \cdot 10^9$ kwh were produced, thus hitting

of needs, one had to built up again the safety margin between needs and output capacity, that was always existing in the past and broke down through events caused by the war. It is known that margin is imperative to can assure a normal electric power supply, owing to the changeable nature of Italian power supplies whose three quarters are covered by hydroelectrical sources and are therefore subject to mutable hydrological events.

1959 has to be looked at as a milestone related to electrical plants, as it saw the completion of many thermical installations, with an output over $1 \cdot 10^8$ kWh and an average generation capacity over $5 \cdot 10^9$ kWh, that is to say an output range that was never reached in the past.

To realize the progress with regard to plants, it is sufficient to remember that at the end of 1959 the whole output of plants generation was twice that available at the end of 1950 and that the available output of thermo-electrical plants at the end of 1959 - which showed a very strong upwards trend in the last years - was more than three times higher than that available at the end of 1950. For the data relating to the building program of Italian electrical firms, see tables II and III.

4) As previously pointed out the building program scheduled in 1956 by Italian power companies for the period 1950-1960

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the top generation level prior to the standstill and to war destructions, and, finally, with 1945, when the generation dropped to only $12.6 \cdot 10^9$ kWh.

is by this time practically completed. In 1956 the power companies members of Anidel were undertaking, with other classes of power companies, the installation within 1960 of an important assembly of new generator plants [1].
It was by then believed - and later on confirmed - that to assure a fit electric power supply, one had to hit towards the end of 1960 an average yearly output capacity of $60 \cdot 10^9$ kWh. Considering that at the end of 1959 - according to a very believable forecast, as ultimate data are not yet available - the average total capacity was hitting yearly about $57 \cdot 10^9$ related to $51 \cdot 10^9$ at the end of 1958; and that at december 31th 1959 plants for over $7.7 \cdot 10^9$ kWh (over a third of which in advanced construction so as to be surely completed within 1960), were being built, it can be concluded that the program scheduled by them, has been realized in due time, also thanks to many additional plants included in the original program.

5) Owing to the oversaid data it may be observed that, at the beginning of 1960; the situation of electric power supplies for the Italian consumers appears to be satisfactory. In a particular way, it can be stressed that, with the safety margin related to hydroelectric generation capacity at a normal level, the available capacity is capable to face the requirements whatsoever, also if we assume a lack of the hydraulic capacity.

Table IV, which reports a calculation of said

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1) : ANIDEL "Relation of the board of directors at member's meeting" - Rome, october 13, 1959.

safety margin, shows that it racked up a substantial rise in 1959 owing to the large increase of thermoelectric power. Its optimal level is therefore generally believed to range between 10 and 15% of average hydroelectric generation capacity.

The favourable present situation is also a consequence of the growing possibility of power exchange both in Italy and abroad, originating from the connection developments with neighbouring countries's networks.

II - 1960 - 1963

1) At this point we may set the question of short-range outlooks both of electric power requirements and availability. Many endeavours have been made in the last years to establish a logical outlook for that demand. The OEEC Electrical Committee, in a particular way, starting from the generation data accertained for 1957, is reaching a production outlook of $53.5 \cdot 10^9$ kWh in 1960 and 61.5 kWh in 1963. The " Three Wises "Committee of "Euratom", reckoning the forecasted nuclear power development, was foreseing for 1960 a generating level of $57 \cdot 10^9$ kWh. The for the Employment and income development Committee[1] - Chairman Mr.Saraceno - starting from the consumptive output data of 1957, is forecasting an output level of $53.5 \cdot 10^9$ kWh in 1960 and $65.3 \cdot 10^9$ kWh for 1963. Other investigations of recent data were foreseing similar development outlooks

1) Employment and income development Committee: "Electrical Industry requirements, generations and investment"(1958--1964), Rome, 1958.

starting from analogous previous statements: ECSC 7%, Little-Rosenstein 6.6 % and Comitato Nazionale Ricerche Nucleari (National Nuclear Research Committee) with 6.8% increase rate.

Table 5 compares actual production needs from 1956-1959 with some of the most reliable budgets forecasted of late.

2) In order to make a forecast of needs developments, the mentioned "Employment and for income development Committee" was perusing the national income increase related to electric power consumption. From that survey, the Committee concluded that, in the present development stage of the Italian economy, the electric power consumption is showing an upwards trend which is slithgly exceeding that of the national icome, i.e. at a rate of 1.4 times. Since the "Schedule" was forecasting a yearly income increase rate of 5 %, the yearly average rise related to the aforesaid 1.4 rate, sums up to 7 %.

We are therefore not far from the truth forecasting a yearly increase rate of 7 %, thus evaluating the needs on about $52.3 \cdot 10^9$ kWh in 1960, $56 \cdot 10^9$ in 1961, $60 \cdot 10^9$ in 1962 and $64 \cdot 10^9$ in 1963 (see table I.)..

The assumption of an increase rate equalizing a doubled figure within 10 years, does not seem unlikely at all related to the present trend. That assumption was, on the other hand, backed also by OEEC, who approved that

the development outlooks of the past years have been overrun by the facts; in some OEEC meetings it had been even emphasized that by cause of the persistent demand in some countries, the putting-out-of-service of may old fashioned units had to be differed [1].

Besides, the above agrees with the conclusions of the "Robinson Commission"[2], forecasting in a research on a survey of general electric power consumption behaviour, that the European countries's economies will benefit for the future from a long-range rate exceeding that they were realizing prior the war : and that therefore decisions on economic policies, with special regard to energetic ones, had to take care of such outlooks.

3) At this point it seems useful to peruse, for the same period previously considered (1960 - 1963), the outlooks related to an output capacity rise proportionated to the continuous increase of needs and to the maintenance of that safety range between forecastable needs and plants capacity, that is a base for regular electric power supplies. The latest analytical data published by Anidel state that the generator plants on construction at december 31th, 1958 show an average yearly output capacity of $13,581 \cdot 10^6$ kWh ($4,931 \cdot 10^6$ hydroelectric and 8,650 thermoelectric). From said total, according to a reliable prediction

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1) See "L'industrie de l'electricité en Europe", 1957-1975 OEEC, 1958.

2) See "L'énergie en Europe - Nouvelles perspectives" OEEC, 1960.

and for lack of conclusive data, plants for an average yearly capacity of $5,833 \cdot 10^9$ kWh (i.e. $777 \cdot 10^6$ hydroelectric and 5,056 thermoelectric) started in 1959. The total capacity of Italian electric plants, that at December 31th 1958, totalized $51,060 \cdot 10^6$ kWh, was thus hitting $56,900 \cdot 10^6$ at december 31th 1959, in front of needs covering about $48,900 \cdot 10^6$ of kWh.

At the beginning of 1960 were then on construction plants covering an average yearly capacity of $7,748 \cdot 10^6$ of kWh (i.e. $4,154 \cdot 10^6$ hydroelectric and 3,594 thermoelectric). That figure is probably lower than the true one, in the run of 1959 new plants having been no doubt installed which are not scheduled so far. Since it is believable that the mentioned plants will be all completed within 1963, the total capacity at the end of this year would hit at least $64,641 \cdot 10^6$ kWh. But even such figure does not give a true picture of the situation, as additional plants whose building works were not initiated at the beginning of 1960 might be completed.

We are therefore not far from the truth, foreseing that said plants may procure a new yearly output capacity up to $6 \cdot 10^9$ kWh. . It follows that the expected output capacity of about $64.6 \cdot 10^9$ kWh availabe at the end of 1963, will hit not much less than $70 \cdot 10^9$. Since the probable needs in that year were supposed (see table I) to hit about $64 \cdot 10^9$ kWh, related to a yearly increase rate of 7 %, it is clear that supplies will be even in that period capable to meet needs with a safety margin as much higher than that available at the end of 1959.

It may be note that said outlooks are prudential in all respects since, as already stated, they relate to plants and equipments already started and apply, only for a very small share to works at hand; moreover may additions chiefly of average and small size, that will be no doubt realized, have not been included in the oversaid outlooks.

4) When tracing a picture of the electric power availability outlooks at 1963, cannot neglect the possibilities of nuclear power. Those have to be, however, evaluated very prudentially because of the many still lasting uncertaintis related to plants installations and production costs, in other words with regard to outlooks on the competitivity of the new power source. The last OECE's report in the field of nuclear power [1] reveales that the contribution to the power supplies of West Europe, that may be given by that new power source, could be but very modest one, not only in 1965, but also in the next 10 years. Almost certainly, the nuclear power cost in 1965 will be still much higher than that of power produced by traditional thermoelectric stations; an exception - says the relation - might be represented by those countries, where the hydraulic sources be about to hit their economical utilization limit or where other power sources be lacking or too expensive. It is the case of Italy, where the nuclear power ~~assum~~ can become competitive earlier than in other countries, although not in the run of a few

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1) Please turn over, note 2 pag.7

years and not without entailing substantial efforts, chiefly of financial nature, on the power companies's turn.

5) In practice, three nuclear plants are in a realization stage in Italy, i.e. the nuclear power station of SELNI (a Company to which are joined some private firms chiefly of the electric field), that will care the installation in North Italy of a station with a net capacity power of 160,000 kWe. Another enterprise is headed by SENN (a Company to which are partaking many firms headed by IRI), that will realize at the mouth of the Garigliano river (Campania), a station with net capacity of 150,000 kW. Another enterprise for the construction of a station in Latina with a net capacity of 200,000 kWe is taken by AGIP. The management will be committed to SIMEA.

Of the said three designs at least two, i.e. SIMEA and SELNI, are likely to be finished within 1963, when some electric power of nuclear origin should be available covering a yearly quantity around $2 \cdot 10^9$ kWh [1]. The average yearly electric power in Italy at the end of 1963 - forecasted above in a quantity covering $70 \cdot 10^9$ kWh per annum - is therefore supposed to be further increased, hitting a yearly total of about $72 \cdot 10^9$ kWh (see tables IV and V)

6) Relating to the above forecasts, backed to a large extent by true facts, concerning the probable development of

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1) It must be stressed that that plants have to be run, for, reasons of economy, at a high load factor.

generating plants, the generating output available at the end of 1963 would schedule 59 % for hydroelectric plants (in 1959 : 66 %); 38 % for traditional thermoelectric plants (in 1959 : 34 %), and 3 % for nuclear plants. On the ground of the programs in realization stage it is to be seen a clear trend towards a larger covering of the needs by thermoelectric plants. Said since some time lasting trend is caused by the graduated lack of economically utilizable hydroelectric sources. In the successive years the utilization of hydraulic sources will hit more and more an economic limit and the new plants will cover but a small share of the new plants's total and become almost disregardable, while the share of conventional and nuclear power plants will get more and more substantial.

7) To summarize, it can be believed that, related to a yearly 7 % rise, the Italian electric power needs will hit at the end of 1963 a level covering $64 \cdot 10^9$ kWh per year, so that to face those needs and in consideration of some large nuclear power stations that will have entered into operation in the meantime, in 1963 the total supply of electric power is supposed to hit about $72 \cdot 10^9$ kWh.

Moreover, at that date the safety margin related to needs would keep a quite sufficient level to warrant in all events a regular electric power supply. Depending upon the share of thermoelectric plants on total generating plants, the aforementioned safety margin will obviously show a drop.

It may be concluded that the present balance

between needs and generating capacity is appointed to keep alive also in the next four years, provided presently not foreseeable happenings.

It also follows that, at least in a short future, the present Italian situation does not call for new additional power sources in addition to the conventional ones. In the nuclear field, an intensive study, research and planning program headed by the power companies should prevail on the building program of large power plants, that are still entailing a very substantial economic risk and should therefore be faced chiefly in view of acquiring necessary service experiences.

8) It is now interesting to look at forecastable needs of investments related to plants to be completed at 1963. In 1954 the financial needs forecasted for the electrical sector faced by the " 10- Years development plan" and related to particular assumption of same, amounted to a total figure $5.13 \cdot 10^9$ dollars to be invested from 1955 to 1964 in generating, transport and distribution plants, a yearly average of about $513 \cdot 10^6$ dollars. After six years and considering the present situation, the figures reckoned by said plain have no doubt to be checked [1].

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1) As it is known, the "10-years development schedule" was fixing the average cost of electric plants at that period a set out hereunder:
hydroelectric storage stations: 0.128 dollars/kWh/of output
hydroelectric flow water stations : 0.088 dollars/kWh of output
Thermoelectric stations : 176 dollars/kWhefficient power transport and distribution network
Hydroelectric power : 0,096 kWh of output
Thermoelectric power : 0.080 kwh of output.

As to the thermoelectric plants, particularly open to engeneering progress, an average capital charge of 136 dollars[1] per kW of capacity instead of 176 dollars, is likely to closer fit the true situation.

For the hydroelectric plants it must be considered that, firstly, the development given to their transport and distribution facilities was lesser than that given to generation facilities and that, on the other hand,in many districts with low consumption and use data the economic progress will lead in short to an increase both of use and consumption, thus entailing a modernization of transformation and distribution facilities networks. It is interesting to stress that in many places there is a trend for shifting from outmoded open wire system networks to aerial cable networks and it is believable that said trend will grow more and more in future, thus entailing very expansive transformations of distribution equipments. As to the general consideration that thermal stations are dropping the distribution and transport charges being located nearer to the centers of use, it must not be overseen that that consideration has no absolute value, as the present trends prefer to have the thermoelectric stations installed on the sea shores in view of a more economic feeding of fuels. For the transport and distribution step, the following data are reliable : 0.096 dollars for producible hydroelectric kWh and 0,080 dollars for thermoelectric kWh.

1) In the above mentioned report of the Robinson commission is forecastead an average cost of 140 dollars per kW for countries belonging to OEEC.

For nuclear plants, an investment forecast is extremely uncertain: according to the calculations of the Robinson report +), an approximatecost of 320 dollars per kW is foreseen.

Summarizing, the average installation cost of electricity stations are reckoned as set out hereunder :

Hydroelectric stations.....0.104 dollars/kWh producible
Thermoelectric stations .... 136 dollars/kW of capacity
Nuclear stations..... 320 dollars/kW of capacity
Transportand distribution networks :
For hydroelectric power.....0.096 dollars/kWh producible
For thermoelectric power... 0.080 dollars/kWh producible

9) Now the unit values have to be transferred on plants to be realized within the 4-years-period under examination, that is to say, related to hydroelectric generation plants, to a total output capacity of $4,854 \cdot 10^6$ kWh (figure that includes those are being built at december, 31th 1959 and those of imminent building); related to thermoelectric generation plants, to a total capacity of $1,594 \cdot 10^6$ kWh (figure including the plants being built at december 31th, 1959 and those of imminent building); and, finally, related to nuclear plants with a capacity of 350,000 kW, whose operation we assume starting within 1963;.

Likewise we will apply the unit values for calculating the financial needs for transport and distribution plants, i.e. at a capacity rate of $4,854 \cdot 10^6$ kWh for

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+) According to said report, for those plants charges for about 450 Dollars per kW, reducible to 300-350 Dollars after 1965 are, forecasted. Those figures are not including the initial cost of nuclear fuel.

hydroelectric; $8,144 \cdot 10^6$ for conventional thermoelectric and $2,100 \cdot 10^6$ for nuclear power plants.

Obviously it has not to be forgotten that a share of those plants was financed in the past, not that in the period under examination the plants appointed to get operation in the following period shall be financed. However, as it is not possible to forecast a reliable schedule of progressive getting-into-operation of the plants, the two overmentioned factors are likely to compensate each other.

A total picture of the aforementioned financial needs is shown on the table VII; the total needs appear to be about $2,188 \cdot 10^6$ dollars, about 833 of which for generation plants and about 1280 for transport and distribution plants, with an average of about $528 \cdot 10^6$ dollars per annum. As we have repeatedly explained before, that figure is assumed lower than that reflecting the true situation.

III - 1964 - 1970

1) Useless to say that whatever long-range term is subject to changes. The chief question to which a satisfactory a priori answer appears difficult, is that whether the trend towards a doubling within a 10 years period, related to electric power consumption and assumed for 1960-1963 too, may be available also in the following period, or whether a stepwise saturation of requirements at a short-time range shall be faced. That was the problem which had to be faced by the Hartly Committee[1] in 1956, when

1) See "L'Europe face à ses besoins croissants en énergie" OEEC, 1956

they tried to outline the of electric power requirement developments in Europe and which lead them to choose, besides a forecasted rise of a traditional 7% per year, a different assumption of a much lower rate, amounting to 5,5%. In 1958 the Electricity Committee of OEEC has, however, studied the problem once more, forecasting that the present increase rate should last unvaried at 1965 and break down step by step in the next ten years [1].

In this connection it must not be forgotten that the economic development is quicker in underdeveloped countries and slower in overdeveloped countries. It is therefore to assume that the electric power consumption, which is in Italy by far lower than that in countries where industry is developed on a larger scale [2], should increase, at least for 10 years, at a comparatively larger rate than in those countries.

2) It must be also underlined that in the South of Italy and in the Islands the power requirements are rising particularly quickly since, as it is known, they are backed by a large helpaction undertaken by the Italian Government through the "Cassa del Mezzogiorno" and supported by leading private concerns, chiefly of the industrial field. In those regions, the increase is assumed to remain very high also in the next years. As it appears from Tables IV e VIII, the increase of power consumption in Southern Italy and

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1.) See also "L'electricité en Europe, 9ème enquête - Réalisations et prévisions 1956 - 1963", OEEC, Février 1959 (See table V).

2) In 1957, for instance, the last year when complete data

in the Islands has been comparatively higher than in Northern Italy. Specially Northern Italy shows a lower increase-rate in comparison to the general Italian level owing its higher pre-existing electrification already during the basis year. Central Italy, Southern Italy and Sicily show, on the contrary, a rate that is substantelly exceeding the general Italian one.

Said figures are confirming the forecast of a long-range general requirements increase, not far from hitting a double figure 10 years. Related to generation, one should therefore reach a total power need of $73 \cdot 10^9$ kWh in 1965 and $103 \cdot 10^9$ kWh in 1970, starting from the $48{,}9 \cdot 10^9$ kWh estimated for 1959 (see table 1).[1)]

If that is the forecastable real need, the average generation capacity must be higher if it is to conserve the safety margin already referred to. According to the previous considerations, we believe that said margin will hit at least 10% in 1970, so that for that year a necessary generating capacity of $113 \cdot 10^9$ kWh (see table V) is obtained.

3) In the following we will peruse the outlooks capable to meet those probable requirements " after 1963" related

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are available, we had against pro-capite consumption of 728 kWh/year in Italy, a consumption of 1,179 kWh in Francen 1,481 in Germany, 1,847 in Great Britain and 1,367 k kWh in Austria.

1) Similar figures are shown by a recent investigation, with a forecast of electric power needs in 1965 of $71 \cdot 10^9$ kWh/ /per year, i.e. $46 \cdot 10^9$ covered by hydro plants, 3 by nuclear plants, 2 by geothermic plants an 20 by conventional

to the period 1964 - 1970, which is often referred to with regard to the outlooks on power requirement and needs development in Europe. Also in that case the forecast is but approximative, since too many unknowns of engineering and technical kind affecting the generation and operation of electric plants are to be faced. In this connection we allude chiefly to the continous engineering progress and unforeseable competitivity between the different power sources. We shall, however, try to trace some forecastable development lines related to the concrete Italian situation.

Firstly it is clear that the importance of hydroelectric power generation, as we already pointed out, is by this time likely to drop step by step with regard to future power needs. We see that at the end of 1963, i.e. at the end of the overmentioned 4 years period we have previously considered the completion of the plants which were being built or underway at december 31th, 1959, is likely to have the average generation of hydroelectric plants brought to the substantial level of over $42 \cdot 10^9$ kWh per year. That forecast is lower than the probable true figure, since additional plants of the same kind, for which data are presently missing, might be completed within 1960 - 1963. Owing to the forecast, backed by reliable designs,[1] that the Italian economically utilizable

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plants (see Paretti, Cao Pinna, Cugia, Righi : "Struttura e prospettive dell'economia energetica italiana" (Conformation and forecast on Italian power economy) 1960)

1) See A.Montagna: "Lo sfruttamento delle risorse idroelettriche montane in Italia" (Exploitation of mountain hydroelectric resources in Italy) - Report presented at

hydraulic sources for electric power generation will hit a peak value of $55\text{-}60 \cdot 10^9$ kWh per year at the end of 1963 the exploitation rate would have already hit 70 - 77 % of the total. That means that one would be very close to the economic limit, so that the resources still left at that period would be available only at a much higher cost. In this connection we wish to say that OEEC, in their report mentioned under 1 p.9.), assumed that in 1975 one should hit in Italy the full exploitation of all economically exploitable sources. According to these considerations, it is not hazardous to assume that the output capacity of hydro plants might hit a maximum of $45 \cdot 10^9$ kWh in 1965 and $50 \cdot 10^9$ kWh in 1970.

The endogenous resources are not likely to consent in the next years an electric power production exceeding the present one, which is somewhat higher than $2 \cdot 10^9$ kWh per year. It is therefore probable that for the whole period 1964 - 1970 the generation capacity and the actual generation of these plants will keep approximately the present level.

4) The chief unknowns refer to the share the nuclear power will have to meet the needs in that period. In that connection, we moreover observe, that that new power source will closely depend upon the future behavior of installation costs of plants and their generation, as well as upon availability and price of fuels.

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the 11th Meeting of Italian Engineers 1959.

Also the Economic Committee for Europe (ECE) is forecasting the hydroelectric sources utilization in Italy in $55 \cdot 10^9$ kWh per year .

As far as the outlooks on installation of new plants are concerned, it was previously assumed that two of the mentioned plants, i.e. those SIMEA and SELNI, could be completed within 1963, while the third one, (SENN) should enter into operation during the following period; moreover another similar design (SIMEA - Astura) for an output of 150 thousand electric kW seems underway. Since it is probable that, the comparative situation of costs may lead in that period to the installation of a new thermoelectric capacity, also considering that in our Country the nuclear power may become earlier competitive tham in other countries, it can be assumed that prior to 1970 an additional similar plant, of 150,000 kW too, may be realized.

Therefore, at the end of 1964-1970, one could add, to the $2{,}2 \cdot 10^9$ kWh of nuclear origin immediately available at 1963, additional $2{,}7 \cdot 10^9$ kWh, when a lump production capacity of $4.9 \cdot 10^9$ kWh of nuclear power would be reached at the end of 1970. We wish to emphasize that, more than a forecast, it is a hypothesis in order to consent a presumtive calculation of the financial needs for the electric plants in the next 10 years.

5) While the hydraulic and nuclear plants may hit in 1970 a capacity of about $55 \cdot 10^9$ kWh/per year, the traditional thermoelectric plants will have to cover the remaining needs (about $113 \cdot 10^9$ kWh) i.e. about $56 \cdot 10^9$ kWh (see table V), in consideration of the foreseeings that the present favorable state of necessary fuel supply will persist. As a fact, if West Europe will not be hurt by

serious pertubating events, chiefly of political origin, an always larger supply of coal and specially liquid and gaseous hydrocarbons is foreseable. As to oil, owing to continuous researches, many new sources have the stocks of raw crude-oil steadily increased. The last sources were discovered in Sahara and are located in a very favourable geographical position for transportation to Europe. Moreover, also the refinning capacity is quickly speeding up in Italy and all European contries.

In French Africa too large quantities of methan were being found; the design of their transportation to Europe by gas pipelines or methan tankers is underway. Italy finds itself in a geographically favourable position for importation of african hydrocarbons. Ii is to be noted too that an international policy is underway to facilitate and liberalize the products exchanges between the various countries.

6) That beforesaid, it does not appear less difficult to determine the financial needs for the electricity plants to be ready in the period under examination. Particularly hazardous is the forecasting of installations unit cost of the various plants. Regarding the hydroelectric plants, we have already seen that hydroelectric resources still to utilize after 1963, will be more expensive and less convenient from the engineering standpoint. A forecasting of an installation cost rise per unit ammounting to 0.120 dollars per producible kWh instead of 0.104, appears therefore quite reasonable. The substantial rise is also

supported by the fact that the hydroelectric power generation will then have to cover more and more the peak requirements, so that one shall dispose of storage hydroelectric power the cost of which is notoriously very high.

An opposite trend will probably prevail related to installation costs of conventional thermoelectric plants, chiefly owing to the continuos improvements engineering in course, which will further cut down said costs. For the period under examination a cost per unit of 128 dollars per kW, instead of 136 dollars, as it was for the foregoing period, has therefore been forecasted.

As far as nuclear plants are concerned, it is hazardous to apply to the whole period the lowest figure forecasted by the Robinson report (300 dollars/KW), so that the value of the former period (dollars 320/KW)will be applied.

Regarding costs of transport and distribution equipments, we believe that the value per unit foreseen for the period 1960-1963 applies also for 1964-1970.

7) By those costs and by the foreseable development of needs, one would hit, for the period 1964-1970, the probable total financial need would hit $5339 \cdot 10^6$ of dollars of today about 1864 of which for generating plants and 3473 for transport and distribution equipments. An average investment of $761 \cdot 10^6$ per year of today dollars would therefore be involved[1]. A summary of said needs for the

1) The Electricity Committee of OEEC show in its 9th investigation the approximate investments in the electricity field. For Italy they sum up to $640 \cdot 10^6$ dollars per year for 1959-1960 and $800 \cdot 10^6$ dollars per year in 1961--1963, however with exception of nuclear investment.

period under examination is outlined on Table VIII. Even in that case we have to consider that a shafe of the plants completed in that period was partially financed in the former one and, moreover, that in the years before 1970 an additional investment quote should be reckoned for the plants, that should be finished in the following period.

At this point it is to be noted once more that the above figures are but approximated, since a long-renge forecast of the financial needs is impossible without a very large approximation margin. It is however interesting to remember that investments in the abovementioned period 1960-1970 in the electricity field is very close to the yearly 5% rise forecasted by the Vanoni plan for development of national revenues at 1964.

IV - CONSIDERATIONS ON THE POSSIBLE INSERTION OF NUCLEAR POWER

1) In the foregoing chapters we have tried to foresee the importance the nuclear power could assume in Italy according the increase of electricity needs and load characteristics; presently we will examine t... problem under a different point of view: what could be the possibilities of setting up nuclear power stations according technical considerations and the situation of Italian industries relating to these new facilities and what would be the convenience of doing so accounting the competitivity factors of nuclear fuels and traditional ones.

In 1956, however, following some political events and some indactions about the future supplies of traditional fuels, it was believed necessary and convenient to set up in Italy 6000 MW of nuclear power in 1975, the first half

of which should be of "english type" (i.e. with natural uranium, graphite moderated and gas cooled reactors), and the second half of "american type" (PWR or BWR reactor stations).

The general state of energy source revealed itself however successively different from the foreseeings: though assuming the law of doubling of electricity needs each ten years to be still in Italy, valid, we now must face a rate of discovery of new oil deposits in the world up to a doubling over each five years, as well as the coal supply crisis in the ECSC countries (see also chapter III, section 5).

For said reasons installations on a large scale of nuclear plants are not likely to be any more so convenient: in fact, since at this moment some price dropping is taking place on traditional fuels, a state of fluidity is advancing owing to that drop and to technologic progress on conventional thermoelectric plants, so that it would be rather riskful to point almost exclusively on nuclear power plants. Moreover the problem would arise of marketing the surplus of fuels oil due to the importation of the raws necessary to face the national needs of other oil derivates (gasoline, gasoil, liquid gases, ecc.).

2) The general problem of inserting nuclear sources into the electric power generation stated, in advance, we are going to examine in detail what are for Italy the most convenient types amongst the different nuclear plants. In our country there was a very strong trend towards natural uranium, graphite moderated and carbon dioxide cooled reactors. Such preference was essentially due to the hope of feeding

said reactors with Italian uranium : at 1957 it was in fact forecasted to can rely upon a yearly production of 65 metric tons of metallic uranium, which would have hit 130 in 1961 (Ippolito F., the Italian nuclear program; Ingegneria nucleare, vol.I pag.20) and, an isotopic enrichment plant not being available not even on a European scale, the best solution appeared that choosen by UKAEA.

The oversaid foreseeings have not been confirmed by the real situation, so that today the problem of choosing amongst natural uranium and enriched uranium reactors becomes once more topical. An in practice fuels have to be imported, it appears evident that the second generation of nuclear power stations (we consider as belonging to the first one the three stations SIMEA,SENN and SELNI which ought be entered into operation within 1963) should point on the advanced enriched uranium reactors with the following advantages:

1) - Lower capital cherges
2) - Better plant flexibility
3) - Better thermodynamic efficiency (Nucleonics, June 1958)
4) - Possibility of a much higher burn-up of fuel than in natural uranium and graphite reactors;
5) Possibility of insertion into the European Communities relating to reprocessing of exhausted fuel and,therefore, to evaluation of the generated plutonium
6) Slower obsolescence of plants.

The solution of natural uranium could be viceversa considered if heavy water were used as moderator; but that product is for the time being monopolized.

Owing to the intrinsic state of the nuclear plant problem and the present insufficient preparation of the national industry, we may for certain that even with reactors of the second generation, the cost of nuclear power will be higher than that of conventional power.

3) Since we think that in principle electric power of nuclear origin will compete with traditional power only when higher temperatures will be hit in the main circuit by technologic improvements, or when "breeder" reactors will be realized, utilizing entirely the plutonium and the thorium cycles, we believe the installation of nuclear power plants in Italy will then pay also from the economic standpoint.

Furthermore, by then, not only the technical features of the plants relating to fuels and reutilization of irradiated fuel will grant favourable market conditions for nuclear plants, but also the Italian industrial concerns will have got acquainted with the new technologies and be, therefore, in a position to manufacture at home parts of plants or special materials, which are presently available only in some foreign countries.

The above foreseeings on the development in Italy of nuclear power application can be summarized as follows:

1st step, when the Italian heavy industry will be capable to manufacture speedily the conventional sections of nuclear power stations (turbines, heat exchangers, thermal shields);

2nd step, when the heavy industry will be prepared to manufacture some parts for nuclear power stations, which are required by the latest techniques (manufacture and

welding of large pressure vessels, high precision valves, etc.);

3rd step, when it will be possible to manufacture in Italy the fuel elements and various parts of the reactor cores, by processing and purifying to the required degree all involved materials, thus importing, if necessary, only the raws not available in Italy, through the supply agents of the various comunitary Organs (EURATOM, IAEA; ENEA). Finally, the light and intermediate Italian industry is no doubt capable of tuning up all necessary technics for the instruments and controls to meet the general reactor requirements.

To conclude, in Italy a favourable situation for the installation of nuclear power stations is likely to come forward not in a long run, should, the following conditions will be verified:

1) The technological progress of power reactors consenting a much larger irradiation of nuclear fuels on the present one;
2) A familiarization of the Italian industrial concerns with the new technics and technologies, so as to enable them to meet to whatever requirement of the markets, both national and supernational.

4th what is left to examine is the installation in Italy of nuclear plants for steam generation and ship propulsion, which might be of interest for the industries calling for steam heated not over 300-350°C (textiles, pharmaceutics, foodstoff, papermills).

It may be convenient to examine whether those plants pay from the economical point of view : the production cost of 1 kg steam at 3 kg/cm^2 at 200° C in a boiler with conventional fuel, whose capacity is assumed to be 60,000 kg/h, changes depending on the load factor, as appears from table IX. (Arcelli G.: Possibility of application of industrial atomic power. - Economia Internazionale delle Fonti di Energia, - anno II n. 6).

Let us now examine a nuclear plant of the type on design at Bell Corp. which can produce the same steam quantity, at 10,5 kg/cm^2 and 180° C, with a thermal power of 40 MW. The reactor is of the pressurized water type and consists of a highly enriched uranium zone (load = = 10 kg) and one of uranium oxide (load = 1,700 kg); the data change as per table X.

The foreseeings may of course still improve in favour of nuclear plants, should the power be risen and if it were possible to have the plant always run at high load factors.

At this point we will point out that the problem could be perused according to a coordinated indutrial development[1], say a system which would concentrate several complementary industrial activities from the season standpoint, so as to realize the two oversaid conditions : high power

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1) In order to express the problem from a quantitative point of wiev, we give some statistichal data relating to 1958 (see table XI). - It appears that the load factors of particular branches are very low, much more than competitivity limits we assumed for nuclear heat generators.

and high load factor. We see in fact that the power needs of a paper mill, industry with a fairly regular operation cycle, requires a daily production of 300-330 paper tons with an average load factor of 0.70 - 0.75 still too low to support decidedly a trend towards the nuclear solution.

As we have seen, the problem of thermal power generation for industrial applications is no doubt very complicated; we could repeat almost the same considerations we have fit for the use of nuclear steam generators for ship propulsion. The interest of Italian shipowners for the nuclear solution might in first time point on tankers, in order to obtain rapid transports of high quantities of raws, without leaving a large tonnage share to fuel oil for propulsion. At the time being, it seems that the nuclear propulsion of a tanker could be competitive, if the propulsion unit cost be not higher than the double of the classic propulsion unit price and if transport charges and quotations of fuel oil will meet with certain conditions[1]; how that may be, the above considerations about the application of nuclear reactors to electric power generation are still valid in the regards of necessary engineering progress in reactor building and, last but not least, the general bahaviour of Italy's industry to fit the new problems and requirements, taking also in consideration the heavier risks involved by ship reactors.

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1) OEEC, L'industrie devant l'énergie nucleaire, 1958, pag.236

Table I

Development of electric power generation in Italy

Year		Generation 10^6 kWh	Generating capacity need 10^6 kWh	Yearly increase on preceding year %
1953	Final values	32,619		5,76
1954	" "	35,574		9.06
1955	" "	38,124		7.17
1956	" "	40,593		6,48
1957	" "	42,726		5,26
1958	" "	45,491		6,47
1959[1]	" "	48,886	56,900	7,46
1960	Forecasting values	52,300		7.--
1961	" "	56,000		7.--
1962	" "	60,000		7.--
1963	" " "	64,200	72,100	7.--
1964	" "	68.700		7.--
1965	" "	73,580		7.--
1970	" "	103,000	113,000	7.--

1) - Temporary figure

Table II

Building program of Italian Power Companies

Efficient power of new plants entered into operation

Year	Hydroelectric plants	Thermoelectric plants 1)	Total	Consistence Year end
1954	387,355	55,195	442,550	10,602,775
1955	443,402	99,825	543,227	11,106,621
1956	766,660	272,435	1,039,095	12,157,686
1957	418,130	105,509	523,639	12,668,045
1958	546,973	518,754	1,065,727	13,750,053
1959 2)	285,631	1,011,152	1,296,783	15,046,836

1) Geothermics included

2) Temporary figure.

Table III

Building program of Italian Power Companies

Generation capacity of new plants entered into operation

(10^6 kWh)

Year	Hydroelectric plants	Thermoelectric plants [1]	Total	Total year end generation capacity
1953	1,600	1,600	3,200	37,000
1954	1,250	1,750	3,000	40,000
1955	1,100	900	2,000	42,000
1956	1,920	1,180	3,100	45,100
1957	1,340	460	1,800	46,900
1958	1,430	2,723	4,160	51,060
1959 [2]	777	5,056	5,833	56,893

1) Geothermic plants included

2) Temporary figures.

Table IV

Needs of electric power supply

10^6 kWh

Year	Needs (generation)	Total output capacity at beginning of year	New units entered into operation	Output capacity			Safety margin on hydroelectric output capacity
				Total		hydroelectric intermediate	
				at year end	intermediate		
a	b	c	d	e	f	g	$\frac{f-b}{g} \times \frac{h}{1} 100$
1953	32,619	35,000	2,000	37,000	36,000	28,825	11.7 %
1954	35,574	37,000	3,000	40,000	38,500	30,375	9.6 %
1955	38,124	40,000	2,000	42,000	41,000	31,450	9.2 %
1956	40,593	42,000	3,100	45,100	43,600	32,900	9.1 %
1957	42,726	45,100	1,870	46,970	46,035	34,600	9 .6 %
1958	45,492	46,970	4,090	51,060	49,015	36,000	9,8 %
1959 1)	48,886	51,060	5,833	56,890	53,975	37,100	13,7 %

1) Temporary data

Table V

Outlooks on electric power needs

(10^6 kWh)

Year	Actual needs (generation) kWh-10^6	Industry and Trade Ministry[1]	Three Wises[2] (1957)	Saracene Committee[3] (1958)	OECE[4] (1959)
1956	40,593	39,200	-	-	40,593
1957	42,726	41,600	-	-	42,726
1958	45,492	44,200	-	46,500	45,330
1959	48,900[5]	47,000	-	49,800	49,500
1960	-	50,000	57,000	53,300	53,500
1961	-	-	-	57,000	55,890
1962	-	-	-	61,000	58,000
1965	-	-	74,000	-	-
1970	-	-	102,000	-	-

1) See report of the Committee for electric power problem designs (Commissione Santoro) - Rome 1954.

2) See "An object for Euratom", reported presented by L. Armand, F. Etzel and F. Giordani - 1957.

3) See "Electrical Industry's requirements, generation and investments" (1958 - 1964), Rome 1958.

4) See "L'industrie de l'electricité en Europe - 9 ème ehquête- OECE, Paris, 1959.

5) Temporary item.

Table VI

Index numbers of electric power consumption related to geographical distribution

(referred to 1946=100)

Geographic distribution	1947	1952	1953	1954	1955	1956	1957	1958
North Italy	112.75	162.69	171.53	182.81	199.32	214.47	225.06	237.41
Middle Italy	153.85	275.40	296.86	327.04	350.31	377.57	407.75	431.06
South Italy	145.94	239.30	264.51	293.50	309.94	329.69	358.69	377.87
Sicily	134.17	251.07	283.10	343.53	390.52	451.38	492.84	558.17
Sardinia	132.79	208.47	216.19	228.79	238.83	263.61	283.75	280.91
I t a l y	120.18	182.30	193.94	209.16	226.70	244.17	258.71	273.19

Table VII

Financial needs for electricity plants in 1960 - 1963

	Hydroelectric		Thermoelectric		Nuclear		Totals
	10^6kWh	$10^6$$	10^3kW	$10^6$$	10^3kW	$10^6$$	$10^6$$
Generation plants	4.854	504,8	1.594	216,8	350	95,2	216,8
Transport and distribution equipments	4.854	465,9	8.144	651,5	10^6kWh 2.100	168,-	1285,44
Total		970,7		868,3		263,7	2102,24

Table VIII

Financial needs for electric plants in 1964 - 1970

	Hydroelectrical		Thermoelectrical		Nuclear		Total
	10^6kWh	$10^6$$	10^3kW	$10^6$$	10^3kW	$10^6$$	$10^6$$
Generation plants	7.600	912	6.320	806,96	450	76,8	1.797,76
Transport and distribution equipments	7.600	729,6	31600	2512	10^6kwh 2.700	216	3.473,60
Total		1641,6		3320,96		292,8	5.271,36

Table IX

Load factor	0,5	0,6	0,7	0,8	0,9	1
Yearly generation (kg)	260	312	364	416	464	515
Steam cost (mills/kg)	2.72	2,64	2,60	2,50	2,55	2,51

Table X *)

Load factor	0,5	0,6	0,7	0,8	0.9	1
Yearly generation (kg)	260	312	364	416	464	515
Steam cost(mills/kg)	3.71	3.10	2.72	2.32	2.08	1.89

*) We assumed a burn-up of 30 %, an incidence of 19 % of capital cost and an engagement of two fuel charges per year.

Table XI

Statistical data on power consumption by some industrial branches in 1958

Branch	Capacity (MW(t))	Utilized output kWh·10^6
Steel industry	120.4	445.1
Mechanical	109.8	129.2
Chemical	165.8	324,4
Oil and natural gas	123.4	307.4
Textiles	182.2	277.5
Food-stoff	185.3	179.1
Papermills	50.9	179.5
Other industries	84,3	131.1
Totale	1,022.1	1,973.3

STAFF NOTE. --Wade Dickinson, a nuclear engineer with Bechtel Corp., San Francisco, Calif., was requested and agreed, in a private capacity, to summarize some of the unusual factors which could influence the competitive costs of conventional and nuclear power in the years ahead.

LETTER REPORT ON POWER GENERATION TECHNOLOGY
By WADE DICKINSON

Several weeks ago you asked me to consider for the McKinney Panel some of the unusual factors which may influence the competitive costs of conventional and nuclear power in the years ahead. To permit a basis for reasonable projection, this summary discussion is focused on the 1960 decade only. Several aspects of three areas of power technology are summarized: conventional power plants, bulk power transmission, and nuclear power plants.

Probably the most important contributor to the advance of power generation technology is the gradual evolution of technical improvements rather than any startling new development, at least in terms of a ten year frame of reference. Nevertheless, with the increasing number of new power generation concepts, particularly stemming from military development, there are two additional important varieties of technical improvement: Expanded or scaled up applications of advanced concepts just now coming into first commercial demonstration or application, and, new developments which are not yet reduced to large scale commercial practice or even demonstration. Often it is hard to distinguish between a new idea and the logical evolution of an older one; I have included a number of items which probably are more evolutionary than revolutionary.

Conventional Power Plants

Peaking Units - As power systems and as consumer markets develop, a general problem of supplying high, but relatively short-lived diurnal, electrical peaking demands is becoming more important. In many areas the available peaking capacity from older high heat rate plants, which have been a primary source of peaking capacity in the past particularly if no hydro were available, is inadequate. The essence of the problem is that most of the customers who create the peaks purchase electric energy on an

energy-delivered (kilowatt-hour) rather than a demand charge (kilowatt) basis. But, utility plant investment is based upon demand (kilowatts). Several promising peaking solutions are under intensive development: packaged diesel engines, gas turbines, jet engines, low cost peaking steam plants, pumped storage hydro, and interruptible industrial plants. With the exception of the jet engine scheme, none of these represent really new peaking concepts, and most of them are applicable for small power plant operation other than peaking on a fairly wide scale.

Packaged diesel engines in standard modules containing several units and making up plants up to 6000 kilowatts, are being proposed for end-of-line, low load factor peaking service. These machines are remotely operated power plants, operating at a fair heat rate - 10,500 to 11,000 Btu per kilowatt hour. Based upon mass production techniques developed to supply units for the railroad industry, the installed unit cost may be brought as low as $85 per kilowatt with switchgear. Such small peaking plants can be placed near the load, thus reducing the transmission costs. Such plants can also aid distribution voltage regulation.

Two varieties of gas turbine peaking plants are being considered. The first is the simple cycle, industrial unit in modules of 5000 to 20,000 kw. The second, more novel concept utilizes an aircraft jet engine as a hot gas generator. For peaking, the advantage of both approaches lies primarily in their very low requirement for cooling water and their capability for remote automatic operation.

With the large scale production of military and commercial aircraft jet engines, several serious programs are underway (and in one case operating) to use a standard aircraft jet engine as a high pressure hot gas generator, the exhaust of which drives a separate gas turbine and electric generator. These units, ranging up to possibly 20,000 kilowatts, may have comparable or possibly lower installed capital cost than diesel peaking units. Their big asset is the availability of a proven, highly engineered product for which production tooling exists. Also, compared to diesels, the capacity of single jet engine-generator units is larger.

Over the past decades, to achieve higher efficiency steam pressure and temperature have been pushed to 5000 psi and 1100 F, with one unit designed for 1200 F. For peaking steam plants, a step backward in performance is being taken. Reduced steam conditions (less than 1000 psi, 1000 F), simpler and less costly steam cycles and elimination of some auxiliary equipment result in plants with poor heat rates but with installed capital cost under $100 per kw.

Another peaking steam plant variant envisions a conventional high performance plant which is provided with considerable excess boiler, turbine, pipe and pump capacity so that some of the heaters may be bypassed, the throughput of the boiler and turbine considerably increased, and the capacity of the unit significantly raised at a sacrifice of unit efficiency. Although it is common steam plant practice to increase unit capacity at the expense of efficiency by bypassing heaters, this type of peaking plant has a much greater built-in overload capability.

Pumped hydro peaking approaches the problem from a different aspect - energy storage. The concept generally embodies creation of a relatively low storage capacity reservoir, although any reservoir may be used, which is filled by water pumped during off-peak conditions. This pumped water is then released through the pump now operating as a turbine or a separate turbine to generate power over the system peak to transfer effectively off-peak excess capacity to cover peak demands. The impact of pumped storage is twofold - peaking and raising the load factor of other system generation capacity.

A last approach to peaking capability, which could also serve as energy storage, is much more conjectural - electrochemical devices or fuel cells. Although the art of making electric storage batteries and electrochemical reduction cells is highly refined, little has been done with electrochemical energy generation techniques. The big attraction for fuel cell power supplies is their independence from Carnot cycle efficiency limitations. However, fuel cell development is really just beginning and large capacity or large scale applications of fuel cells to commercial power production will probably not come into being in the next decade.

The fuel cell actually has two potential peaking capabilities: first as a direct conversion device of fossil fuel or chemicals into electric energy; second, as an energy storage device which couples electrochemical dissociation by off-peak electric energy, subsequent storage of the chemicals produced and on-peak recombination of the chemicals to produce electric energy. Little work is underway on the latter concept; but overall there appears to be a good prospect that economically feasible non-reversible fuel cell systems, at least for small (kilowatt level) power demands, should evolve. Present effort is being concentrated upon hydrogen-oxygen fuel cell systems, which are near practical fruition for military applications.

Use of off-peak or interruptible electric energy in electrochemical or industrial plants which would in turn be shut down during the utility system peak will help alleviate some peaking problems. A basic limitation to this scheme is the requirement for a chemical plant or manufacturing process which can easily, safely and quickly shut down or start up and which can stand the economic loss of such a shutdown. The basic

economic justification for this concept is that the interruptible power supply could effectively pay the capital cost difference between a stripped, high heat rate but low cost peaking plant ($90/kw) and a higher cost, most efficient power plant ($130/kw). The more costly high performance capacity is justified by the interruptible load causing an increase in the unit capacity factor from the 10-20% range to the 70-90% range.

Combined Steam Turbine - Gas Turbine Cycles - Much research throughout the world has aimed at joining the complementary characteristics of gas turbines and steam turbines. Plants using a gas turbine as an auxiliary component drive or separate power producer, wherein the hot gas turbine exhaust is discharged into a conventional boiler to serve as a preheated air source and forced draft fan, have been analyzed and seriously considered. The overall efficiency improvement of such combined cycles, however, has not yet been shown to be sufficient to justify widespread application. Moreover, the concept for the present is limited to fuels such as gas or refined fuel oil.

A different approach which offers a promise for coal is a coal gasification unit wherein the gas formed is burned in a gas turbine to produce electric power. The coke residue is ground hot and used to fire a conventional steam boiler. Thereby it is possible to burn coal indirectly in a gas turbine and simultaneously combine the gas and steam turbines. The result is a net increase in plant efficiency of about 5% with a slight capital cost increase over a non-combined cycle.

Plant Automation - Over the next decade there will be an increasing incidence of partial or complete power plant operation, regulation and data recording by electronic computer type devices. At present, incremental loading of several power plants on a system to provide the lowest overall system power generation cost is being successfully used. As well, several machines are being installed to provide automatic data-logging and some interpretation so that more detailed and accurate analysis of power plant performance and operation can be achieved. The first plants embodying automatic startup and shutdown supervision are under construction and more widespread application should result over the decade. The impact of increased power plant automatic control is closer supervision of a very wide variety of plant variables, safer more reliable operation of high performance equipment, and probably more economic operation.

Tidal Power and Geothermal Power - Aside from pumped storage hydropower, tidal hydropower has been widely discussed throughout the world. Under special conditions, it appears that some tidal power plants could be built. But it does not appear that much, if any, tidal capacity will be constructed over the next decade because the total potential

capacity is not large and the economic incentive does not appear great.

Another limited application, but potentially important power concept for some areas, is geothermal or natural steam power. Several large plants are now in successful operation and other sites will very probably be developed.

Magnetohydrodynamics - Much study and some research effort is underway on magnetohydrodynamic generation techniques. The devices envision a stream of very hot ionized gas moving across a magnetic field. Within the field, charge separation of the ions occurs which in turn represents a potential or voltage difference that may be used if the separated charges are connected across an external load. The very hot gas passing out of the device may also be used to generate steam fpr a conventional power plant. The temperatures necessary to produce an adequately ionized gas could conceivably be produced by combustion or nuclear techniques. However, work is just beginning on the concept and it appears doubtful that practical power plants of utility significance based upon such techniques will be forthcoming in the next decade.

Coal Pipe Lines - Pumping coal-water slurry for long distances under varying climatic conditions has been demonstrated over the past few years by the success of the over one hundred mile long Consolidation Coal Company coal pipeline to a Cleveland Electric Illumination Company plant. This fuel transport concept competes with and is potentially lower in cost than rail movement; moreover, no car return problem exists. As well, it may offer greater freedom in siting coalfired steam power plants in that sites remote from existing fuel transportation systems may be supplied by a pipeline. The major problems are the requirement for a large water supply near the coal source and dewatering of the coal at the termination of the pipeline.

Power Transmission Systems

The progress of high voltage transmission can be viewed as an evolutionary development. Over the past years transmission voltage has been progressively stepped up until today 345 kv is being used. Even higher voltages are being experimentally developed throughout the world. With growing power loads, individual steam turbine generator units are also growing larger in capacity because of the economies of scale. To a lesser degree, units are growing larger in physical size. But, concurrently, technically suitable thermal power plant sites are becoming less available; and those sites that are acceptable are often far from load centers. The result is that transmission lines are growing both in capacity requirements and in length. Additional problems which compound the transmission pro-

blem are that with burgeoning suburbs, right-of-way is often difficult to purchase. Thus existing rights-of-way or rights-of-way combined with other utilities must be used. The result again is an emphasis on bulking more power over a given transmission line. All of these factors combine to indicate that extra high voltage (EHV) alternating current transmission and possibly high voltage direct current transmission will become more common and more widely applicable in the 1960's.

For EHV, the major problems of corona discharge (radio noise), insulation, and conductor design will probably be in hand above the 345 kv level during the coming decade. For d-c transmission, the basic limitation is the requirement for high efficiency, high capacity, but low cost rectifiers andinverters since there is no application for high voltage d-c and since a-c is necessary for voltage transformation. The cost of this specialized d-c equipment, compared to other transmission means, does not yet appear to be competitive. However, in some special situations such as long underwater cables, d-c has proved to be less costly than multi-phase a-c cables.

A factor which can have an important long range impact on high voltage d-c transmission is the development of high efficiency, solid state rectifier-inverter systems. These units are basically similar to solid state diodes. In small units they can serve as d-c transformers. (When used as a d-c transformer, the direct current is first chopped into a-c, transformed to a higher voltage, then rectified at that higher voltage to provide effective d-c transformation.) Present capacity of solid state inverter-rectifier units is limited to a few kilowatts although it appears quite possible that much larger units can and will become economically available during the coming decade.

Nuclear Systems

Very Large Plants - The most significant factor about nuclear power over the next decade is the advent of firm priced plants (about $200 per kw) having net fuel costs of about 3 mills per kilowatt hour. (There is good prospect that both lesser fuel costs and capital costs may be achieved.) In many areas of the world having high and rising conventional fuel costs such nuclear power plants are presently competitive with conventionally generated power.

The principal factors requisite to achieving this goal of competitive nuclear power are that the nuclear unit be large, that it be run at high load factor, and that the plant be located in an area of high conventional fuel costs. To achieve firm capital costs of about $200 per kilowatt, nuclear unit sizes of about 300 emw are necessary. At the present time, only water

reactors are being offered at these prices and in these unit sizes. There is a good possibility that the cost of water systems will be reduced even further and that other types of reactor systems can be similarly offered in the 1960 decade. Nevertheless, it must be realized that the number of utilities or power systems capable of accepting as much as 300 emw in one unit are limited. (EHV transmission could be an important factor in broadening this large reactor market in that groups of smaller utilities could commonly operate a single unit.)

The second important criterion for competitive nuclear power is high capacity factor. To take advantage of high capacity factor, nuclear fuel costs must be lower than conventional fuel costs otherwise there can be no economic offset to the higher capital cost of the nuclear power units. Today with $200/kw and 3 mill/kwh fuel, nuclear power can be competitive at high capacity factors with conventional plants having fuel costs of about 45¢ per million Btu. To achieve the requisite 80% capacity factor and preferably 90% capacity factor, either the using power system must be large compared with the nuclear unit size, or some energy storage device like pumped hydro or possibly reversible fuel cells is necessary. Unfortunately, many areas of the world having high fuel costs where nuclear power would at first appear most competitive, also have the most difficulty in maintaining a high system load factor and high unit capacity factor. Many of these high fuel cost areas would also find it difficult to accept single units as large as 300 emw. This places strong emphasis on combined hydro-nuclear plants or energy storage concepts.

Escalation - A unique economic characteristic of nuclear power plants and hydro plants is that a relatively high proportion of total energy generation costs result from capital costs, as compared to fossil fueled plants. Thus a large proportion of total energy generation cost is insulated from inflation, once a plant is built. The opposite condition of a nuclear plant being more subject to inflation if construction is delayed will be offset, at least in part, over the next decade, because of the reduction in nuclear unit capital costs from technical improvements.

Nuclear fuel costs are already less than some conventional fuel costs. Three important factors will tend to reduce nuclear fuel costs further and thereby serve to counteract any inflationary effects. First, fabrication costs, which for slightly enriched uranium oxide fuel represent about one half of total fuel cost, are decreasing quite rapidly with increased production knowledge and volume. Second, the general trend of natural uranium cost is strongly down because of world oversupply. Depending upon the degree of enrichment used, this variously affects fuel costs but certainly indicates a downward trend over the coming decade. Finally, the expected burnup for slightly enriched fuel within the next decade is

increasing, thereby giving hope of 20,000 megawatt days per ton or more if this be desirable depending upon system optimization.

New Containment Concepts - Although in some circumstances it may be possible to eliminate complete containment vessels for some well-tested reactor systems, containment very probably will remain for most nuclear units over the 1960 decade. Various reactor containment innovations, particularly applicable to water reactors, should provide even greater assurance of safety but even with improved containments the most important factor assuring the safety of utility nuclear plants will be the experience of having built and operated several variants of each of several basic reactor types.

Containment improvements generally aim to quench the mixture of steam, water, and air created by an accident within a containment vessel rather than contain these vapors at high pressure. (This condition results from the steam and water being released from the reactor coolant system in a Maximum Credible Accident.) Three approaches are being designed or considered. The first embodies a direct cycle boiling water system placed in a sub-grade, high pressure caisson which is vented by large ducts to an adjacent water filled tank. If a break in the primary piping or loop occurs, the steam and flashing water pass over into the quench tank and are condensed there. Most of the activity is therefore trapped in the sealed, shielded water of the quench tank. What little of the contaminated vapor bubbles through is held at low pressure in the shielded, gas-tight space above the quench water in the tank.

The second design envisions placing open, water filled vessels within a containment to cool the water-steam mixture so that much lower containment pressures result.

A third containment variant embodies water sprays inside the containment. These sprays scrub and cool or condense the materials released in an incident. All these schemes reduce the pressure head or dispersive force which might serve to distribute fission products throughout or around the containment.

A major result of these containment concepts will, very probably, be the construction of large nuclear power plants in or near large population centers during the next decade. More overall freedom in power plant site selection should result.

Radioactive Primary Systems - Nuclear fuel can probably be described as exquisitely inspected, beautifully manufactured and quite costly. A possible reactor system development of the next decade may be

the acceptance and design of primary loops to function normally in a rather highly contaminated condition resulting from operation with several or even large numbers of partially failed fuel elements. (The Pressurized Water Reactor is already designed to operate with 1% of the fuel elements failed.) Other units are designed for normal operation with a comparable proportion of failed elements. Although not all of the facts are available it appears quite possible that shielding and safety systems can be designed to permit practical operation in a rather highly contaminated condition. It is also likely that equipment of adequate reliability and quality to require very little access can be commercially produced. Requisite complementary developments are advances in decontamination materials and procedures. The potential impacts of using radioactive primary loops are these: Many of the benefits of fluid fuel systems (principally low core cost) may be achieved with fewer problems such as corrosion. Second, core manufacturers' tolerances and inspections may be reduced with resultant reduction in fuel fabrication costs. The major uncertainty is the balance of operations and maintenance costs versus core costs, all in terms of the activity level maintained within the reactor coolant.

Increased Power Density and Nuclear Superheat - Reactor pressure vessel diameter is in general a limiting factor to water reactor unit power output. Increased core power density both by flux flattening and greater heat removal and transport techniques will help to take advantage of the available pressure vessel technology. By such techniques the power density of commercial water reactor cores should about double over the next decade.

Nuclear superheat offers another approach to improving nuclear plant performance and nuclear unit output. Because of reactor vessel limitations the steam pressure of water reactor nuclear plants will probably remain low (1000-1500 psi) as compared to modern conventional plants. Superheat thus offers the only hope of increasing the steam enthalpy for water reactors. With superheat, lower cost steam turbines can be used with the larger water reactor nuclear units because the steam flow required per kilowatt capacity is reduced with the higher energy content of superheated steam, as is the problem of handling the excessive moisture produced within a saturated steam turbine.

Cycle efficiency rises with steam superheat and further reduces equipment size per kilowatt. Many steam components are reduced in cost per unit capacity although the higher temperature requirements for some components requires more costly equipment. The net effect of nuclear superheat for water reactors is reported by various reactor manufacturers to be a potential decrease of as much as one-half to one mill per kwh.

Gas cooled reactors offer another promising avenue to higher steam temperature. The basic advantage of a gas cooled reactor stems from its capability of producing high coolant temperature (up to 1400 F) at a reasonable pressure within the reactor vessel (a few hundred psi). With such coolant temperature, steam conditions comparable to modern conventional units (1000 F to 1050 F at high pressure) can be produced and reactor power densities (10 kw per liter and more) comparable to other systems can be achieved. Thereby the steam using portion of a gas cooled nuclear plant can make use of the most advanced, high performance turbines and other steam equipment.

Thermionic and Thermoelectric Conversion - Thermionic and thermoelectric devices for direct conversion of heat into electricity are being intensively studied on a laboratory scale. Thermoelectric devices are essentially semiconductors across which a temperature difference is placed. This results in a potential (voltage) difference, a flow of current and in turn a net power output. The thermodynamic efficiency of these devices is limited principally by the temperature differences which can be effectively applied across a given thermoelectric material. Considerable progress is being made in developing higher operating temperature and higher overall efficiency thermoelectric materials. (Present military technology falls in the 2-10% efficiency range.)

Thermionic devices, which superficially can resemble a diode vacuum tube, make use of a very hot (2000-3000 F) high electron work function electron emitter placed closely adjacent (a few thousandths of an inch) to a cooler (500-2000 F), but still hot, lower work function element. The space between is either a vacuum or filled with an ionized vapor such as cesium to neutralize space charge effects. These units should provide direct conversion efficiencies of 15-40%. (Greater than 15% has already been demonstrated.)

Both thermoelectric and thermionic devices can be used within nuclear reactors to convert fission heat directly to electric energy. An important aspect of thermionic equipment is that nuclear fuel materials such as uranium carbide are directly adaptable as hot elements. With both types the cool element or clad is still sufficiently hot such that high temperature steam can be generated directly or indirectly by the required cooling thereof. Thus the whole element can be combined into a direct conversion nuclear fuel element wherein the heat source is the nuclear fuel and the cool element is in contact with or is actually the fuel element cladding.

With thermionic and thermoelectric direct converters, a nuclear power unit has a potential efficiency level in excess of fossil fueled plants because the direct conversion power contribution is additive to the

steam cycle power output. It should be noted that 40% net cycle efficiency is now almost a barrier for conventional plants because the efficiency improvement of higher performance steam equipment does not in most cases appear to justify its incremental capital cost. Direct conversion devices may permit breaking this barrier. But even with the rapid advance of this technology, commercial or utility scale development has not yet even begun so that it is doubtful that direct conversion nuclear or conventional systems will be used for commercial or utility application over the next decade, other than experimentally.

Energy Storage - Basic to continued application of nuclear plants is a problem stemming from their high capital cost characteristic - the necessity for base loading these nuclear power units. Thus the peaking problem or poor system capacity factor applies even more strongly to nuclear plants. Two solutions have been discussed - pumped hydro and fuel cells. The latter may be integrated with a reactor. One approach would utilize direct dissociation within a reactor to produce storable chemicals as a product of the dissociation. These chemicals could be recombined on-peak in a fuel cell to produce electric energy. As another approach, the d-c product of internal direct conversion could be used directly as low voltage d-c to dissociate chemicals outside the reactor which could in turn be recombined in a fuel cell to cover peaks. Very probably neither of these concepts are practicably realizable in the next decade for commercial utility application.

Fusion Systems - The best characterization of fusion power is a plot of project enthusiasm versus time wherein the present depths of despair seem to exceed past peaks of optimism. Even though it appears possible that fusion systems producing net power output may be achieved in the next decade, it does not appear probable that fusion power will become an important, or in fact, any factor in fulfilling the capacity demands of the coming decade.

Summary

The foregoing represents some of the salient technical and economic concepts which are applicable worldwide, both to conventional and nuclear power generation over the next decade. In general, the availability of peaking power plants and EHV transmission will serve both nuclear and high performance conventional plants, since both of the latter are high capital cost units. If anything, the nuclear plants will be more favorably affected by any concept improving unit capacity factor. Plant automation is probably more directly adaptable to nuclear plants than conventional plants since, by the very nature of having a radioactive heat source requiring totally remote control and instrumentation, a nuclear plant is both

capable of and designed as a highly self-controlled and automatic unit. Thus nuclear plants should offer even greater possibility for totally automatic operation.

Although thermoelectric and thermionic direct conversion devices can be applied both to fossil fueled and nuclear plants, they appear more applicable to a nuclear heat source. With fossil fuel, all of the heat must be transferred from the point of chemical reaction in a difficult physical environment to the hot element; whereas the nuclear fuel element can be in direct contact with or actually be the hot element itself.

Over the next decade, the relative economic position of nuclear plants should improve compared to fossil fueled plants. A major deterrent could be the continuation of accelerated world petroleum discoveries which could tend, as it already has in some parts of the world, to delay the rise in nuclear capacity. But with the continued growth of power systems and the availability of $200/kw (or less) large nuclear plants with 3 mill/kwh (or less) fuel, it appears that the rate of installing nuclear capacity over the 1960 decade should be steadily upward throughout much of the highly industrialized world.

Section B

FUELS—CONSUMPTION AND AVAILABILITY FOR 1975 AND 2000

For Robert McKinney Study Group by W. C. Schroeder, Chemical Engineer, Department of Chemical Engineering, University of Maryland, College Park, Md., May 1960, under AEC Contract # AT-(49-13)-1727

Summary

FUELS—CONSUMPTION AND SUPPLY FOR 1975 AND 2000

The lives and well-being of the people in the countries of advanced industrial development are dependent on a constant and uninterrupted flow of thermal, electrical, and mechanical energy. By far the larger part of this energy has come, and will come for a long time in the future, from fossil fuels. With national existence at stake, each country must provide not only for its current demand but also as far as possible for the future.

Most of the industrial nations are now experiencing rapid population growth, which, coupled with increasing energy consumption per capita, leads to a sharply growing energy demand. In addition, many of the poorly industrialized nations are more and more aware that they can and must improve their living conditions and economic position. This creates large energy demands in entirely new areas.

On one hand this ever-growing use of energy raises the fear of a worldwide fossil fuel shortage and on the other a shortage in individual areas or countries.

It is the purpose of this study to examine both these questions.

Much of the data used in the report were prepared by or for the Robert McKinney study group. Other data were taken from scientific literature. Sources are indicated.

Opinions are those of the author, although in most instances they coincide with opinions expressed in the original reports. Where substantial disagreement exists, this is pointed out.

Coal

World consumption for coal, petroleum, and natural gas are shown in Table I. The great coal-consuming nations of the world are the United States, O.E.E.C. (Western Europe), the U.S.S.R., and China. Total world consumption is estimated at 2,300 millions tons for 1960. The world over, consumption of coal is advancing much less rapidly than for oil and gas, and in some countries it is not believed that it will grow very much above present levels. World consumption for 1975 is estimated at 3,300 million tons and for 2000 at about 4,000 million tons.

In the United States coal consumption has fallen from a peak of 600 million tons in 1948 to 450 million tons. The writer believes that production will rise to about 560 million tons by 1975 and to nearly double this by 2000. This increase is predicted largely on the growing use of coal in the electric power industry and for metallurgical purposes.

A second larger user of coal is the O.E.E.C. nations. Traditionally they have depended on coal for energy, but now this picture is changing, and they are turning to oil and gas. Estimated coal production

for 1960 is 560 million tons. This is expected to increase only slowly, reaching 580 million tons by 1975 and 600 million tons by 2000. The reasons for this slow growth are difficult mining conditions and high coal costs in much of the O.E.E.C. area on one hand, compared with low-cost oil from the Middle East and possibly later from the Sahara on the other hand.

TABLE I.—*World consumption for coal, petroleum, and natural gas*[1]

Country	Coal (millions of tons, 2,000 pounds)			Petroleum (millions of barrels)			Natural gas (billions of cubic feet)		
	1960	1975	2000	1960	1975	2000	1960	1975	2000
United States	450	560	1,000	3,700	6,700	14,000	12,400	26,000	52,000
Canada	31	50	100	300	650	1,700	500	2,000	5,500
Caribbean	5	5	5	250	600	1,200	380	550	1,300
Other Americas	5	5	5	220	540	1,500	90	200	800
OEEC (Western Europe)	560	580	600	1,100	2,200	6,000	1,400	3,500	9,000
Middle East	(2)	(2)	(2)	150	300	600	(2)	(2)	(2)
Africa	50	50	50	70	150	500	(2)	(2)	(2)
Far East	120	130	150	270	920	4,000	(2)	(2)	(2)
Australia and New Zealand	28	28	28	80	170	500	(2)	(2)	(2)
U.S.S.R. and satellite countries	715	1,000	1,130	1,100	3,700	7,400	1,700	15,000	36,000
China	355	920	[3] 1,000	28	350	[3] 1,000	(2)	(2)	(2)
Total	2,319	3,328	4,008	7,284	16,280	38,400	16,370	45,250	104,600

[1] Assembled from data indicated in detailed sections of the report.
[2] No data or consumption small.
[3] Minimum.

Much of the coal consumed in the Far East is used by Japan and India. Generally, coal costs in these areas are high and coal is imported. It is not anticipated that consumption will grow very much in the future, but rather that oil will carry the burden of increased energy requirements.

The U.S.S.R. and satellite countries now have the largest coal consumption in the world, and about 65 percent of this is in the U.S.S.R. Some growth is anticipated to 1975 and 2000, but the burden of increased energy demand will fall on oil and gas.

Available data for China indicate substantial coal consumption for 1960, with a planned increase of considerable magnitude by 1975.

World coal reserves are shown in Table II. This estimate is very conservative and indicates recoverable coal with present mining practices and costs comparable with those of today. If the need arises, much more coal than this can be found.

On a world-wide basis the reserves are ample to support production to the end of the century. To look at the major nations, and considering mining and transportation costs, the United States is probably in the most favorable condition. Reserves are ample to support any foreseen production for about 200 years. They are also well distributed over the country with some of the best coal near the major centers of consumption. Mining conditions are good and costs have been kept low. It is not anticipated that real costs will rise substantially in the future and they may decrease.

TABLE II.—*World reserves of coal, petroleum, and natural gas*[1]

Country	Coal, proved reserves (billions of tons, 2,000 pounds)	Petroleum (billions of barrels)		Natural gas (trillions of cubic feet)	
		Proved	Potential	Proved	Potential
United States	250.0	38.2	240	260	1,000
Canada	30.0	4.6	60	26	100
Caribbean	2.0	22.0	120	40	300
Other Americas	.5	2.8	80	10	250
O.E.E.C. (Western Europe)	180.0	1.6	18	5	50
Middle East	(2)	182.0	560	230	2,000
Africa	20.0	6.6	90	5	250
Far East	80.0	10.0	70	10	150
Australia and New Zealand	14.0	(2)	(2)	(2)	(2)
U.S.S.R. and satellite countries	270.0	31.0	120	53	700
China	100.0	(2)	(2)	(2)	(2)
Total	946.0	299.0	1,358	639	4,800

[1] Assembled from data indicated in detailed sections of the report.
[2] No data or reserves small.

Overall reserves of coal in the O.E.E.C. area are ample to support estimated production well beyond the end of the century. Much of the reserve is well located near consuming centers. Mining costs now appear to be coming down.

The U.S.S.R. has ample coal reserves, although the satellite nations are not in as satisfactory a position. A good deal of the U.S.S.R. coal is not well located with respect to centers of use and long hauls are necessary. Mining costs are reasonable and it is believed they will go down in the future.

Petroleum

Total world consumption of petroleum is estimated at 7,000 million barrels for 1960, 16,000 million barrels for 1975 and 38,000 million barrels for 2000. All industrial areas of the world indicate greatly increased consumption over the next 15 and 40 years.

The United States is the world's largest producer and consumer of petroleum. Consumption by the end of the century is estimated to be about three times the present consumption. In the past the United States has been a large scale exporter of petroleum and its products. Since 1949 this situation has changed and the country is now an importer.

Canada is also a consumer and producer with prospects for rapid increases in production which will permit this country to become a large scale exporter.

The Caribbean is largely a production area, supplying Europe and the United States.

Other American areas, which include much of South America, import oil, but some countries, such as Peru, are exporters.

The O.E.E.C. countries expect petroleum consumption to grow by about 5 fold by the end of the century. These countries are of course importers of oil on a large scale, although in recent years they have had indigenous production amounting to about 9 per cent of their total consumption.

The Middle East is the great source of supply for oil for many areas of the world, including O.E.E.C., Africa, South America, and the Far East.

Africa is now an importer of oil and consumption is expected to grow rapidly to the end of the century. This continent is also becoming a producer on a substantial scale.

Most of the nations of the Far East import oil and the demand is substantial and growing rapidly. A few of the countries, such as Indonesia, are exporters.

Australia and New Zealand are consumers only and have no oil production.

Oil consumption in the U.S.S.R. and Satellite Countries is large and is expected to increase about 7 fold by the end of the century. Much of the energy for increased industrial output will be provided by oil. The U.S.S.R. is also becoming an exporter of oil on a considerable scale.

Little is known about oil consumption in China, although a considerable expansion is planned by 1975.

World reserves of petroleum are shown in Table II and are classed as proved and potential. The proved reserves are those which have been found by drilling and which can be recovered by present day technology at about present costs. Under normal conditions this represents the working inventory of the petroleum industry. There is no need to drill and "prove up" more oil when the inventory is satisfactory. In the United States proved reserves have usually been about 10–15 times annual production.

Since petroleum is such a vital energy commodity there has always been a strong desire to know the total resources of a country or area in order that due warning could be raised when there was imminent danger of exhaustion. This conception is incorrect, and exhaustion of petroleum from a large country is virtually impossible. New places can always be found to explore and very likely some oil will be found. Furthermore, fields which no longer flow prolifically can be worked by secondary recovery methods and more oil can be obtained. While the exhaustion of oil is not a threat, the question of the cost of finding and producing the oil is of real concern. Therefore, any attempt to evaluate the potential reserve of a country must be concerned with reserves that can be found and produced at reasonable costs. So far as possible the potential reserve estimates in Table II are on this basis.

On a worldwide basis the ratio of proved reserves to production for 1960 is about 40 to 1. These are sufficient to carry forward to 1975. Additional reserves will, of course, be added during this 15-year period. It is estimated that potential reserves that may be expected to be found are over 1,300 billions of barrels.

For the next 25 years to the end of the century potential world reserves indicate that demand can be met and up to the year 2000 potential reserves are estimated at 35 times consumption for that year. It is obvious that this will require an expanding exploration and drilling program, and toward the end of this period real costs may advance substantially.

Within individual countries there are wide variations in respective positions. In the United States the present reserve and potential reserve picture appears satisfactory. However, due to a long continued and heavy exploration program, oil is becoming more costly and harder to find. As a result the United States has become an importer of oil, and imported oil to considerable extent holds the key to the future position of the domestic oil industry, as well as the coal industry.

Canadian reserves are growing rapidly and it is anticipated that this country will be a substantial exporter in the future.

Potential reserves in the Caribbean area are very large and the export program is expected to grow.

At the present time proved reserves in South America (other Americas) are small but it is believed that the potential is great and that this area will eventually become a large producer and exporter.

Proved reserves in the O.E.E.C. area are small, but surprisingly enough, considerable oil has been found and it is making an important contribution to the energy economy of the area. The potential reserves indicate that substantial discoveries should continue. The O.E.E.C. area is, of course, a large importer, with most of the oil coming from the Middle East.

The Middle East now has by far the largest proved reserves and the largest potential reserves of the whole world. This fabulous area gives every indication of becoming the world's production center. Exploration and production costs in this region are comparatively low and will probably stay low for a long time in the future.

Africa is building up substantial proved reserves of petroleum and the potential reserves appear large. This continent will undoubtedly be able to supply its requirements and will become a major exporter in the future.

The Far East is now a substantial importer of oil. This area has not, however, been extensively explored and the potential is believed to be large. With the growth of industrialization, accompanied by a strong and adequately financed exploration program, this area could become self-sufficient in oil.

Australia and New Zealand are not oil producing countries, although Australia is now reported to have some oil reserves. Exploration is also going on in Australia.

It is difficult to assess the U.S.S.R. because of lack of data, but probably they are able to meet their own requirements for the future, and can well be a large exporter of oil.

With respect to China, no data are available on present reserves. This country covers a large land area and commercial oil production with substantial reserves are to be expected if adequate exploration is carried out.

From this brief review of world reserves and potential reserves there is no reason to believe that oil requirements cannot be met to the end of the century and beyond. It should also be mentioned that in addition to oil many countries possess large reserves of oil shale, tar sands, and coal which can be converted to oil. Technologic developments in recent years show that the cost of doing this is approaching present petroleum costs in some countries.

One of the problems that haunts the oil industry is the danger that a large importing area may be cut off from its oil supply by political unrest, strikes, or riots, excessive taxes, or other acts of the supplying area. This was the condition that Europe was in during the Suez crisis. It is now evident, however, that the world wide scope of the industry makes it possible for increased production at many other locations to step in and fill the gap. Obviously this cannot be done without great strain, but the situation can be met.

At the same time a large oil exporting area cannot shut down exports for any period of time without destroying its own economy. Added to that is the fact that if they fail to supply oil they may permanently lose part of their export business. It is the writer's belief, therefore, that no one area of the world has a command over the flow of petroleum which it can exercise at will over any long period of time.

The above views are not predicated on the assumption of long scale or global war. This would alter the picture completely, since oil producing areas may be physically destroyed by war and it would take a long time to restore production. Also, these areas might fall under control of nations with no regard for the lives or economy of the local people.

Natural gas

Turning now to natural gas, it is only in the United States that this industry has assumed a dominant position, and a good deal of the growth here has been since the war. As shown in Table I, production here is expected to about double in the next 15 years and to double again by the end of the century.

The gas industry is growing rapidly in Canada and with ample supplies is expected to become of great importance.

In the O.E.E.C. area much of the gas now in use is manufactured from coal, coke or oil. Some natural gas has been found and is contributing to the primary energy output.

Russia is laying plans for a tremendous expansion of the gas industry and by the end of the century expects to be using about 36 trillion cubic feet annually.

Table II shows the proved reserves of gas. In the United States at the present time reserves are about 21 times production. Potential reserves are large but the expected increase in consumption is also very large and a strong exploration program will be required to produce the gas needed. It is anticipated that this will have to be supplemented by imported gas, and imports from Canada have already started. At the present time gas is a more difficult fuel to import than oil and for pipelines gas the United States is largely limited to Canada and Mexico. It is anticipated that gas prices will rise in the future.

Canada has large reserves of natural gas now and these are expected to grow with the development of oil production. It is anticipated that Canada will be able to export gas to the United States.

The Caribbean and other American areas have large reserves of gas, which at the present time have no adequate outlet.

The O.E.E.C. area has only small reserves of gas but it is assumed that ultimately natural gas will be brought to this area in a liquefied form by ship; or perhaps by natural gas pipelines from the Middle East or from the Sahara.

The potential Middle East proved reserves are enormous and are seeking outlets.

The U.S.S.R. has large potential reserves and it is presumed that these are sufficient to meet the expected greatly expanded consumption.

Conclusions

With respect to the energy picture as a whole, in the past the United States has had low cost energy—first coal, and then oil and natural gas. During most of this time other areas of the world such as Europe have had high cost coal because of difficult mining and other conditions. They have had little oil and much of it imported from the United States at relatively high costs, and essentially no natural gas. This whole fuel picture is now undergoing great change. The Middle East has the world's greatest proved petroleum reserves and other areas such as Africa may make major contributions. Natural gas is available in great quantities in the Middle East, probably in the Sahara, and important quantities are being found in Europe. Oil and gas can be moved at low cost all over the surface of the globe. Oil by large supertankers and pipeline, gas by pipeline, although even here tankers for cooled and liquified gases are being considered.

It is now hard to conceive very many areas which are important energy consumers which cannot be reached by oil or gas at modest transportation costs. Essentially this means that all over the world the cost of energy will tend to "level up" and that many countries will begin to enjoy advantages in this respect which in the past were those of a few nations, and particularly the United States.

This points to two important considerations for proposed atomic energy plants or, in fact, any other new form of primary energy. First, fossil fuels will be in good supply to the end of the century, without major increases in real cost, and second, and this applies particularly to oil, they can be provided all over the world at reasonable cost. Therefore, any new form of primary energy must compete with fossil fuels; it cannot be looked upon as stepping in to take the place of a fuel whose reserves are being exhausted, nor can it look to find many areas which need large energy supplies which are fundamentally high cost to the fossil fuels.

CONSUMPTION AND SUPPLY FOR NATIONS AND AREAS

Fuel consumption and supply have been examined for the major nations and areas of the world up to 1960, and the writer has attempted to estimate conditions for the years 1975 and 2000. The predictions for 1975 (15 years into the future) are, of course, on much safer ground than for the year 2000.

It was not found possible to follow any standardized procedure for making predictions. A large amount of background data were available for the United States, Canada, Western Europe, and a few other countries on which estimates for future requirements could be based. For many countries there was little reliable data even for current requirements, and predictions for the future are very uncertain. Insofar as possible the expected change in population and in gross national product were weighed in the predictions.

Only the major energy sources are considered, namely, coal, oil, and natural gas. Estimates for coal are based on short tons of 2,000 pounds. Anthracite, lignite and peat are all reported as coal. Oil is reported in terms of barrels (42 U.S. gallons). The average heating value of the oil is estimated to be 5,900,000 B.t.u. per barrel. Liquified petroleum gases are included with oil. Natural gas is reported in terms of 1,000 cubic feet (mcf at 60° F. and 29.9 inches of mercury) and the average heating value is estimated as 1,000 B.t.u. per cubic foot. Hydroelectric power is reported in terms of kilowatt hours.

One of the major factors that must be considered for all fuels is the distribution between coal, oil and gas. Until World War I coal furnished a large percentage of the world's energy requirements. Since that time the use of oil and natural gas has increased rapidly all over the world. This leads to a further important factor, namely, that needs must be met on the basis of particular types of fuel.

For consideration of energy consumption and supply the world has been divided into the following nations or areas:

1. United States.
2. Canada.
3. Caribbean.
4. Other America.
5. O.E.E.C. Nations.
6. Middle East.
7. Africa.
8. Far East.
9. Australia and New Zealand.
10. U.S.S.R. and Satellite Countries.
11. China.

CONSUMPTION AND SUPPLY OF ENERGY IN THE UNITED STATES

Between 1900 and 1920 from 80 to 90 per cent of the energy needs of the United States were supplied by coal. After this the use of petroleum grew rapidly. Natural gas consumption increased slowly until the end of World War II and very rapidly after that. By 1958 the use of the various fuels was approximately as follows:[1]

	Percent
Coal	28
Petroleum	38
Natural Gas	30
Water Power	4
	100

Consumption of coal

The all time peak in coal production was reached in 1947 and 1948, and was about 600 million tons per year. Shortly after World War I coal production had beeen near this same level. In the interval between these peaks, which was the period of the depression, production sank to about half this level.

From 1948 to the present coal utilization has decreased, and the estimated consumption for 1960 is about 450 million tons per year.

Coal has lost many of its important markets to oil and natural gas. These include space heating, both domestic and industrial, railroad

[1] Estimated from Bureau of Mines data. See "Minerals Yearbook, 1957."

locomotives, and ships. In most cases it is believed these markets are permanently lost since there were technical, convenience, or economic reasons for displacing coal in the beginning, and at this time there is little to indicate that these conditions will be altered in the future.

Coal has maintained its position in two fields, for the production of coke for metallurgical purposes, and for the generation of electric power. Coking coal is a specific rank of bituminous coal which is abundant in the eastern half of the United States, but not so abundant in the western part of the country. The use of coal for coking purposes will grow with the steel industry and with other metallurgical applications.

During the past decade a growing interest has been shown in the direct use of gas such as hydrogen or carbon monoxide for the reduction of iron ore. Such gases can be made from natural gas or oil, as well as coal and the widescale application of these new processes could decrease the dependency of the metallurgical industry on coking coal.

Coal's loss of markets in some fields has been partly compensated for by increased use for the generation of electric power. This has occurred in spite of the fact that the utilities during this same period have greatly increased the overall efficiency of electric power generation.

From this analysis of coal's position there is no reason to believe that there will be any substantial loss of the markets for coking coal or coal for electric power generation up to 1975. A projection carried forward to the year 2000 becomes much more uncertain, but coal is expected to dominate the field for electric power generation.

Between 1949 and 1958 the change in coal utilization for various major markets was as follows: [2]

Market	Percent		
	1949	1958	Change
Industrials	26	26	0
Coke	20	21	+1
Electric utilities	18	42	+24
Retail deliveries	20	9	−11
Railroads	16	2	−14
Total	100	100	

For the future the writer anticipates that the use of coal for industrial purposes and for coke will increase slowly, probably around 1 percent per year. Utility use is expected to grow somewhat more rapidly, probably around 4 percent per year. Retail deliveries will continue to decrease, but this market is expected to essentially disappear by 1975. The railroad market is about gone now. It is therefore anticipated that coal utilization will increase only slowly to 1975, and the writer estimates growth at 1.5 [3] percent per year. Beyond this, utilization is expected to increase more rapidly and has been

[2] "Minerals Yearbook," Bureau of Mines, 1958, p. 125.
[3] Percentages are compounded annually.

estimated at 2.5 percent per year. Under these conditions consumption will be as follows:

Year:	*Million tons per year*
1960	450
1975	560
2000	1,000

Supply of coal

More is known about the total cost available in the United States than is known about such fuels as oil and gas. There are two reasons for this; namely, that coal in this country is relatively close to the surface, and the geology is such that it is often possible to estimate or infer the extent of the beds from outcrops or a limited number of cores. Because of these favorable conditions, it is reasonable to believe that there is a good deal of coal still to be discovered and evaluated.

Total coal reserves are now estimated at around 1,500–2,000 billion tons. This includes a great deal of thin and deep coal which is not economically mineable. Mineable coal is estimated at 500 billion tons. Since only about half of this can be mined and brought to the surface, the recoverable coal is in the order of 250 billion tons.[4] Even on the basis of estimated utilization for the year 2000, this coal is sufficient for two centuries or more.

The situation regarding coking coals is somewhat less favorable. The supply is more limited, particularly for those coals of the most suitable sulfur and ash content. It is probable, therefore, that technology for upgrading the coking coals must be developed, and work in this direction is going forward.

The overall amount of coal which has been mined is negligible with respect to total reserves. Up to the year 2000 there should be no general increase in real mining costs because of depreciation in the reserve position. This is not true in local areas, however, where long continued and extensive mining operations have sometimes depleted reserves.

As a whole the coal reserves of the United States are well distributed. About one-third of the recoverable bituminous reserves are east of the Mississippi River, and these are the better grades including much of the high rank coking coals. Shipping distances to major centers of consumption are not excessive. Much of the coal in the western states is in thick seams which can be mined at low cost. As the population grows in the west this coal will be utilized more and more.

During the past 15 years the development of new mining techniques has been exceptionally rapid and in fact has quietly brought about a revolution in coal mining. The machinery for strip or surface mining operations has grown tremendously in size and production in the order of 50 tons per man-day is not unusual. Underground the continuous mining machines have proved themselves to be much more efficient than the earlier cycle of operations in which the coal was

[4] "Resources of Coal, Petroleum, Natural Gas, Oil Shale, and Tar Sands in the United States and Allied and Neutral Countries (March 1960)," Department of the Interior.

drilled and undercut, blasted, and then loaded. Underground production rates of 15 to 20 tons per man-day are not unusual in modern mines.

The effect of these changes has been to hold the price of coal at the mouth of the mine essentially constant for the last 15 years. This has been accomplished in the face of rapidly rising wage and material costs.

It is not anticipated that costs will increase in the next 15 years. Reserves and seam thickness will not change materially. Strip mining operations which now produce 28 percent of the bituminous coal and lignite will grow in a modest degree as more coal is mined in the western part of the country. The application of the continuous miner underground, which now is used on only about one-seventh of the production, will grow rapidly. Production per man day will increase and is expected to offset any increase in wages or material costs.

Between 1975 and 2000 reserves will be ample to allow the opening of mines in new favorable areas as older areas are exhausted. The development of more efficient mining methods is expected to continue. It is possible that during this period hydraulic mining methods will be extensively applied to coal mining. This may include hydraulic transport of the coal to the surface, and to the cleaning plant. Such development would further decrease overall labor requirements per ton of coal mined. It is believed mining costs will hold constant or decrease.[5]

The costs of transporting the coal are of great importance to the ultimate consumer. In 1958 75 percent of the coal was moved by rail and the average cost was about $3.50 per net ton, which is equivalent to the cost of mining in modern operations. Where the coal could be shipped by water rates were lower.

It is reasonable to expect an increase in rail and water shipment costs both to 1975 and beyond. For the large coal users, such as the electric utility stations where coal is fired in a finely pulverized form, other means of transportation are opening up. Pumping the coal with water in a pipeline has been demonstrated as feasible. There is little reason to believe that transport of pulverized coal with gas is not equally possible. These and related developments will be carried forward in the next 15 to 40 years.

Still another approach to the transportation problem is the construction of long distance, very high voltage electric transmission lines. Where water and coal are adjacent, the powerplant can be at the mine mouth and electric power transmitted to the centers of consumption. This eliminates coal transportation as a major cost item.

At this time it is reasonable to believe that transportation problems for coal will not grow more difficult than they have been in the past. Since the utilization of coal is falling more and more into the hands of very large consumers, this offers possibilities of developing new transportation methods which may lower costs.

It is evident that our coal reserves are ample to meet our estimated needs up to the year 2000 and probably for two centuries more. The development and application of new mining methods and improve-

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[5] "Resources of Coal, Petroleum, Natural Gas, Oil Shale, and Tar Sands in the United States and Allied and Neutral Countries," U.S. Department of the Interior, March 1960.

ments in transportation are in an early stage and further major steps forward can be expected. This leads to the conclusion that there will not be increases in the real cost of coal to the consumer within the next 40 years. At the same time, it is evident that neither the amount of coal mined nor its price will be controlled by the size of the coal reserves, but rather by the price and availability of competing fuels.

Consumption of petroleum

The consumption of petroleum and natural gas liquids has increased from 1.3 billion barrels in 1938 to an estimated 3.7 billion barrels in 1960. The growth of the automotive and airplane transportation, the dieselization of the railroads, conversion of shipping from coal to oil, use of oil for heating and power, and the growth of petrochemicals have all contributed to this increase.

In several of these markets oil products are now the only ones which can be used; for example, for automotive and airplane transportation. A similar situation exists for the use of oil on the railroads and for ships. Oil competes with both natural gas and coal for space heating and power, and as a raw material for petrochemicals.

During the past 20 years oil has been taking over markets from coal, particularly home heating and the railroads, which has contributed to the rapid increase in its utilization. Now, these changes are approaching completion and this will be reflected in less rapid growth trend for these specific applications. Since the end of World War II the use of natural gas for space heating has increased greatly, especially for domestic purposes and oil has lost part of this market. Natural gas will continue to take over those markets where its cleanliness and convenience are of outstanding importance.

Growth in oil requirements does not appear to be directly predictable on the basis of per capita consumption and growth in population, nor is it necessarily a function of gross national product. Past trends have shown a growth rate of about 5.7 per cent between 1920 and 1960. For the reasons indicated it is believed this rate will fall to 1975 and growth has been estimated at 4 per cent over this period. Beyond 1975 the growth rate has been taken at 3 per cent, which is about 1 per cent above projected population growth. Under these conditions demand will be as follows:

Year:	*Billions of barrels of oil and natural gas liquids*
1960	14.0
1975	6.7
2000	14.0

Supply of petroleum

Two sources must be considered for petroleum, domestic and foreign. At the present time the United States is importing about 15–20 percent of its supply.

No one knows the total supply of petroleum that may be available in the United States in spite of the fact that this is the most extensively explored country in the world. Also such an estimate would not have great significance, unless at the same time it was possible to determine at what price level various fractions of this total oil could be recovered.

Therefore, and rightly, the petroleum industry does not attempt to talk about the total supply of petroleum. Instead the industry carries out enough exploratory and developmental drilling, year by year, to provide enough operating wells to meet the demand. This has worked well. Up until World War II the United States had not suffered from petroleum shortages, and was an exporter of petroleum and its products on a large scale.

During World War II there were petroleum shortages due to heavy demand abroad and here, loss of foreign supplies, and most important shortage of steel and manpower which would have made it impossible to increase production in this country. The shortages were not caused by lack of petroleum in the ground.

After World War II supply rapidly caught up with demand and little further difficulty has been experienced. Even during the Suez crisis and the dislocation it caused in the world distribution of petroleum, the United States was able to increase domestic output rapidly and to export large quantities. At the present time the proved recoverable reserves of petroleum and natural gas liquids are 38.2 billion barrels, and this estimate is the highest it has ever been. Proved reserves have increased from 24 billion barrels at the end of World War II to 38.2 billion barrels now, and this in the face of the highest production rates in the country's history. Past experience indicates that this can continue at least for the next 15 to 40 years, if we are willing to put forth the necessary exploratory effort. Measured in terms of total wells drilled, the increase has been from 27,000 wells in 1946 to a peak of 57,000 wells in 1956.

The 38.2 billion barrels of proved reserves indicated above are based on the 1959 estimate of the American Petroleum Institute and includes petroleum and natural gas liquids.[6] This estimate is on a conservative basis and is the part of the reserves already proved by drilling which is recoverable by methods currently in use and under current economic conditions. On the basis of industry interviews[7] and taking into account predictable extensions of presently known reservoirs as well as improved technology, it is believed that a more realistic estimate is around 65 billion barrels.

Attempts have been made to estimate the total recoverable resources of liquid hydrocarbons in the United States on the basis of geographical areas that appear favorable to oil production. At the present time the Review Group[8] estimates these at about 240 billion barrels.

The history of the petroleum industry shows that there were more periods in which over supply of oil was a problem rather than under

[6] "Proved Reserves of Crude Oil, Natural Gas Liquids and Natural Gas," Dec. 31, 1959. Vol No. 14.
[7] Report prepared for the Review Group by a Task Force on Basis of Industry Interviews.
[8] Report prepared for the Review Group by a Task Force on Basis of Industry Interviews.

supply. This led to the development of state regulatory bodies controlling production. Over supply is a problem now and many of the most prolific areas are allowed to produce only 9 to 12 days a month.

Does this mean that after all the production and use of oil in this country we are in no different position than we were 20–25 years ago? This does not appear to be the case. The effort to find and produce a barrel of oil is growing greater. Exploratory wells hit less frequently, greater footages are drilled to find a given amount of oil, fewer large fields are found, drilling is carried on in less favorable areas and in areas where costs are higher such as in shallow water on the continental shelf of the oceans and the Gulf. This has led to increased capital investment to establish capacity and to higher costs to produce the oil.

An example of increased costs is the development of production in the waters off Louisiana. After 14 years work total investments are about 2.6 billion dollars, with revenue amounting to 0.725 billion dollars, leaving a deficit of over 1.8 billion dollars.[9] A second cost factor of importance in the United States is illustrated in Figure 1 showing the growing disparity between costs in the United States and the rest of the Free Foreign World. Capital expenditures in the United States per barrel of production are now well over twice the costs in the rest of the Free World.

On the other hand, there are many factors which counterbalance these conditions. There have been steady improvements in drilling operations, including rigs, bits, and drilling mud. Percussion hammer drills, turbine drills, and drilling slim holes have proven advantageous. Methods have been developed for fracturing the formations by hydraulic pressure and this allows increased production from tight formations, or production from formations which were not otherwise commercially useful.

Considerable technologic improvement has been made in the recovery of oil from the formation. In many cases in the past only 20 to 30 percent of the oil in the sand could be produced. Better primary recovery operations, or improved secondary recovery have increased this percentage. Water flooding is now common in many fields. Various chemical agents are being studied which will help the water displace the oil from the sand. Combustion of oil in place as a means for increasing recovery is being tried.

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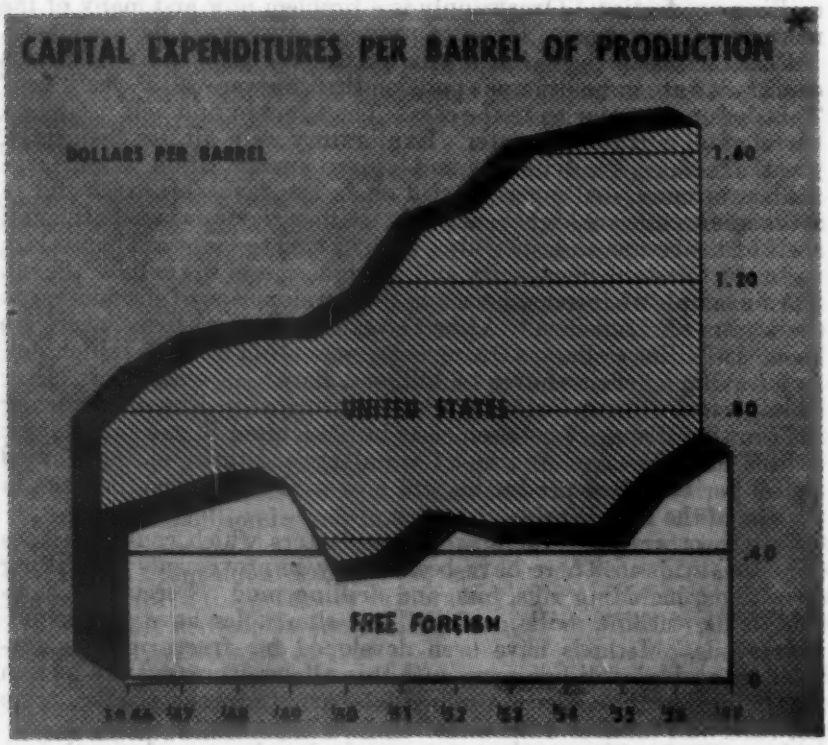
[9] Oil and Gas Journal, May 2, 1960, vol. 58, No. 18, p. 78.

FIGURE 1



*From "Future Growth of the World Petroleum Industry," The Chase Manhattan Bank (1958).

The effect of this technologic progress has been to increase production per well on the average from 11.6 barrels to 17 barrels over a 15 year period.[10] It is believed it will be possible to continue this trend.

On the whole, oil production costs in the United States have shown an upward trend. Since World War II the selling price for petroleum has increased faster than wholesale prices generally. This trend might be reversed by greatly improved methods which would make exploration much more certain, but without this, it would be anticipated that costs would continue to rise.

The Department of the Interior estimates the replacement cost for crude oil in the United States at the present time at $3.38 per barrel. This includes all costs of exploration, drilling, production and royalties. It is believed that production could be increased at this price if this were desirable. In some other major oil areas abroad both replacement and production costs are substantially less.[10]

Actual selling price for petroleum and its products is not entirely dependent on the cost of production in the United States. The transportation of oil by ship and pipeline is convenient and economical, barring tariffs or embargoes, domestic oil must compete with oil from

[10] "Resources of Coal, Petroleum, Natural Gas, Oil Shale, and Tar Sands in the United States and Allied Neutral Countries," March 1960, Department of the Interior, p. 28.

Canada, Mexico, the Caribbean, South America, and the Middle East. These are now the most important sources, although others may arise as time goes on. The sea coast areas of the country are the most vulnerable to this competition; however, oil can go inland from the ports by pipeline without greatly increasing the price.

This points clearly to the concept that there are essentially no areas in the United States which are fundamentally high cost fuel areas. Either ships or pipeline can supply all areas with petroleum. How much the consumer actually pays for fuel may be dependent on how much oil we are willing to import and at what price.

In terms of oil exploration and development, the United States is in a considerably more mature state of development than most of the other major producing areas of the world. In many areas abroad oil is very easy to find and exploratory effort need only be made in those areas which are most favorable. The effects of these differences can be seen in the fact that the average well in the Middle East is now producing 5,000 barrels of oil a day, contrasted with an average of 17 barrels a day in the United States. Proved reserves in the Middle East are nearly 5 times U.S. reserves and are growing rapidly with comparatively small exploratory effort. Capital costs for establishing productive capacity in these prolific areas are less than half the cost in the U.S. This, coupled with low operating costs, gives these areas a substantial advantage, even though they must ship the oil for long distances.

This situation has had three important effects on the oil industry. The United States on a net basis is no longer a major oil exporter, but instead now imports large quantities of oil. Many United States oil companies are conducting extensive operations abroad, and where the political climate remains favorable this offers a considerably better return on invested funds than domestic production. Finally, the domestic industry encounters growing difficulty in competing on a price basis with imported oil.

Because of the military and industrial significance of oil to the United States, this country has favored a domestic industry that could meet its full requirements. At the present time there is no doubt that we have ample capacity to do this. If this policy is to be continued in the future it appears to the writer that imported oil must be controlled to the extent of allowing the domestic industry to continue to grow.

Under such conditions oil shale and coal can probably enter the picture as new sources for liquid fuels. Large scale technology has been developed for mining oil shale and producing practically all petroleum products from the shale oil. Total reserves of the higher grades of shale are in the range of 200–300 billion barrels of recoverable oil. At the present time this could probably be produced at prices about 25 percent higher than the present selling prices for petroleum.

Coal offers further potential sources of liquid fuels. It can be converted to essentially all petroleum products and this has been done on a large commercial scale in Europe. In the past costs have been high, particularly the capital cost for the productive facilities. The processes for this conversion have been extensively investigated and as the result of developments during the past few years very much simpler plans are now possible which can be built at much lower costs. Fur-

ther developments may lower costs sufficiently to permit liquid fuels from low rank coals to compete with domestic petroleum.

Further research on oil shale and coal confirming the present developments would, in effect, greatly increase the domestic reserves of liquid fuels which could be recovered at about present price levels. Also, since the location and extent of large bodies of oil shale and coal are established, this would help to stabilize production costs of the future. Substantial and continued research and development efforts in these fields are justified.

Looking toward the future, there is little doubt that domestic petroleum could meet requirements until 1975 and very probably to the year 2000. It is equally true, however, that the real costs for finding and producing the petroleum would rise during that period and might rise rapidly.[11]

Any rapid rise in domestic prices would, however, create strong pressure for importing greater quantities of lower cost oil from abroad, and it would be anticipated that imports will tend to increase over a long period of time. As will be shown later, the proved reserves of the world are now so great that they can meet world requirements at least to the year 2000 with relatively little change in production costs.

Consumption of natural gas

Natural gas is playing a rapidly increasing part in the energy output of the United States. From 1900 to 1920 gasfields were used to supply nearby surrounding areas, with a total of around 4 percent of the energy output of all fuels. After 1920 the use of gas expanded more rapidly and by 1945 it supplied about 14 percent of the total energy. After the war, and with the extensive use of the very large sized long distance transmission lines, there was further expansion, and by 1960 it was contributing about 34 percent of our total energy. At the present time the use of gas is growing more rapidly than any other fuel.

The development of transmission lines now permits the economical delivery of gas for 2,000 or 3,000 miles to our largest centers of consumption. This fuel is exceptionally clean, convenient and in many cases requires the simplest and least expensive installation for use. These are all factors of great importance to the domestic and often the industrial user. In addition, in many areas of the country gas furnishes the cheapest fuel.

Natural gas is used by three major groups of customers, i.e. domestic, commercial, and industrial.[12] The first two account for about one-third of the gas consumed, but because they pay relatively high prices, they contributed two-thirds of the revenue. Industry, on the other hand, uses two-thirds of the gas and pays only about one-third of the revenue.

The reason for this is that the heavy investment in long transmission lines has encouraged the gas industry to offer industrial users low rates to assist in keeping the lines operating at full capacity.

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[11] This is in disagreement with the viewpoint expressed by Bruce C. Netschert in "Future Supply of Energy Resources," December 1959 (Resources for the Future, Inc.).

[12] Domestic—gas used in residences for space heating, hot water, and cooking; commercial—gas used in stores, offices, service establishments for space heating, hot water, cooking, and small amounts of steam; industrial—gas used in large steam or power plants, and for industrial processes.

This gas is usually furnished to the manufacturer on an interruptable basis so that his supply can be cut off in cold weather, or other periods of heavy demand. This practice is sound from an economic viewpoint, but has led to the accusation that the indsutry is wasting a valuable resource on lower grade uses, simply to keep its pipelines in full operation.

In recent years a partial solution to this problem has appeared in the development of natural underground storage reservoirs in suitable geologic formations which have been found near some consuming centers. At the present time there are over 200 storage pools with a capacity over three trillion cubic feet. The transmission lines can be used during the summer or other periods of low demand to fill these reservoirs, and then in the winter gas is withdrawn to meet high demand. This levels out the flow over the year through the transmission system.

In 1958 gas utilization was divided into the following broad categories:

	Percent
Industrial	57
Residential and commercial	29
Field	13
Carbon black	1
	100

At this time industrial and residential and commercial uses were increasing sharply. Use in the field was increasing more slowly and use for carbon black was decreasing.

For many years gas was regarded as almost a waste fuel. Large amounts were discovered in connection with oil drilling and often more was available than could be marketed.

These conditions no longer exist. Drilling for oil is insufficient to produce the gas needed and the gas industry now carries out its own exploratory and drilling program. The flaring of gas produced with oil is not tolerated in most areas, and gathering systems must be provided.

As a result of convenience and demand, the cost of gas has gone up more rapidly in the last 15 years than either oil or coal. One most significant reason for this is that gas was probably at too low a price level compared to other fuels prior to World War II. Prices would have gone up even faster if this fuel were not subject to price regulation in interstate transmission. So far as the future is concerned, it seems probable that gas prices will tend upward until it is on a competitive basis with other fuels.

The predicted consumption for gas for future years is subject to somewhat greater uncertainties than for coal or oil, since both consumption and price of gas are rising rapidly. Between 1943 and 1958 the average rate of increase in utilization was about 8%–9% per year. It does not seem that this rate will be sustained for the next 15 to 40 years for several reasons:

(1) The program of replacing coal with gas is approaching completion.

(2) Gas prices will tend to rise and be on a more nearly competitive footing with oil.

Taking these factors in account, the writer believes that gas consumption will rise at the rate of about 5% for the next 15 years and then at the rate of 3% to 2000. Under these conditions production will be as follows:

Year:	*Production (trillions of cubic feet)*
1960	12.4
1975	26.0
2000	52.0

Unike other fuel industries, the gas industry since 1945 has not had to await the development of markets. Commercial and industrial customers were often ready for gas before it could be brought to them. Construction of pipelines and distribution systems lagged behind the demand in many areas of the country. This failure to supply service as fast as required did not normally result from lack of reserves, but rather from the size of the financing and construction programs that were required.

These conditions are now changing. Gas has increased in price and consumers are weighing its cost against oil, or in the case of industrial users, against coal. It is also becoming more difficult to find reserves which can be dedicated for 20 or more years to supply a pipeline, and where available, the initial cost may be comparatively high, with escalation clauses that will create still higher costs in the future.

Supply of natural gas

Estimation of the total reserves of natural gas in the United States presents similar difficulties to estimating the total petroleum reserves. The gas industry, like the petroleum industry, does not utilize such estimates, but instead operates on the basis of an inventory position, which normally represents 15 or more years of gas supply.

In the beginning natural gas was essentially a byproduct of the search for oil. Gas might be found without liquid products, which was a great disappointment in those days. However, even where oil is found, a considerable quantity of gas accompanies the oil to the surface, and when the pressure is released, most of the gas escapes. Generally this amounts to 4,000 to 8,000 cubic feet per barrel of oil. In terms of energy, 6,000 cubic feet of gas is about equivalent to a barrel of oil.

Dry gas [13] was used in city gas systems early in the history of the oil and gas industry. This was common practice in Pennsylvania, Ohio, West Virginia, and other eastern states. Some communities still use gas from local areas while others have exhausted their supplies and take gas from the pipelines.

During this period gas produced with the oil was usually flared and wasted. There were no gas gathering lines to the oil wells and there was nothing else to do with it.

With the growth of the long distance pipelines the dry gas wells began to assume real importance and formed the backbone on which the huge investment in the pipeline could be made. It became apparent also that the gas released from petroleum as it reached the surface could be gathered and fed into the pipelines.

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[13] Dry gas is relatively free from liquid petroleum materials such as light gasoline and heavy gases such as propane and butane.

For many years the petroleum industry was the exploration and production arm of the gas business. Gas, where it could be used, added a modest increment to income from petroleum. It sold in the field for whatever it could command, and for years that was often less than 5 cents per 1,000 cubic feet.

This was, of course, only a transient situation. Gas is too fine and convenient as a fuel for such conditions to continue. Pipelines were built between centers of consumption and the producing areas. In states such as California, gas fields were often convenient to larger cities. As time went on, the lines grew longer and finally reached from Texas to New England. At the same time California and parts of the West Coast could no longer meet their own requirements and pipelines were built to the West Coast.

During this period all gas became more valuable. Average value at the wells rose from about 5 cents to about 15 cents per mcf. Average value at the point of consumption rose from 20 to nearly 50 cents per mcf. In particular the big reserves of sweet gas (free from sulfur compounds) which could be dedicated to pipeline use began to move up in price. Field prices moved to 20 cents a thousand cubic feet, and in recent years to 25 cents, with escalation clauses for the future.

The technology of the gas industry began to grow too. Wet gas, containing propane, butane, and light hydrocarbons was washed to remove them so that the gas was ready for the pipelines. Sour gas containing sulfur compounds, which a few years ago would have been worthless, was cleaned up and used. Gas containing carbon dioxide was purified for the pipelines.

Now gas is approaching petroleum in the total energy it supplies to the country. The industry has gradually taken over more and more of its own exploratory and production operations, and this trend will continue.

Figure 2 shows the proved natural gas reserves for the period 1946 to the present. In spite of the rapid rise in production, proved reserves have increased from 150 to 260 trillion cubic feet.[14]

In the lower part of this chart production is compared with additions to proved reserves (extensions and revisions plus discoveries of new fields, and new pools in old fields) for each year. It is seen that additions exceed production for every year with the exception of 1954 when they were about equal.

Attempts have been made to estimate the total gas reserves that may be found in the United States considering all the favorable geographical areas for exploration. It is concluded that this is in the order of four times the proved reserves, or about 1,000 trillion cubic feet.[15] The economic costs to find and produce all of this gas are unknown, but would be expected to be higher than present day costs.[16]

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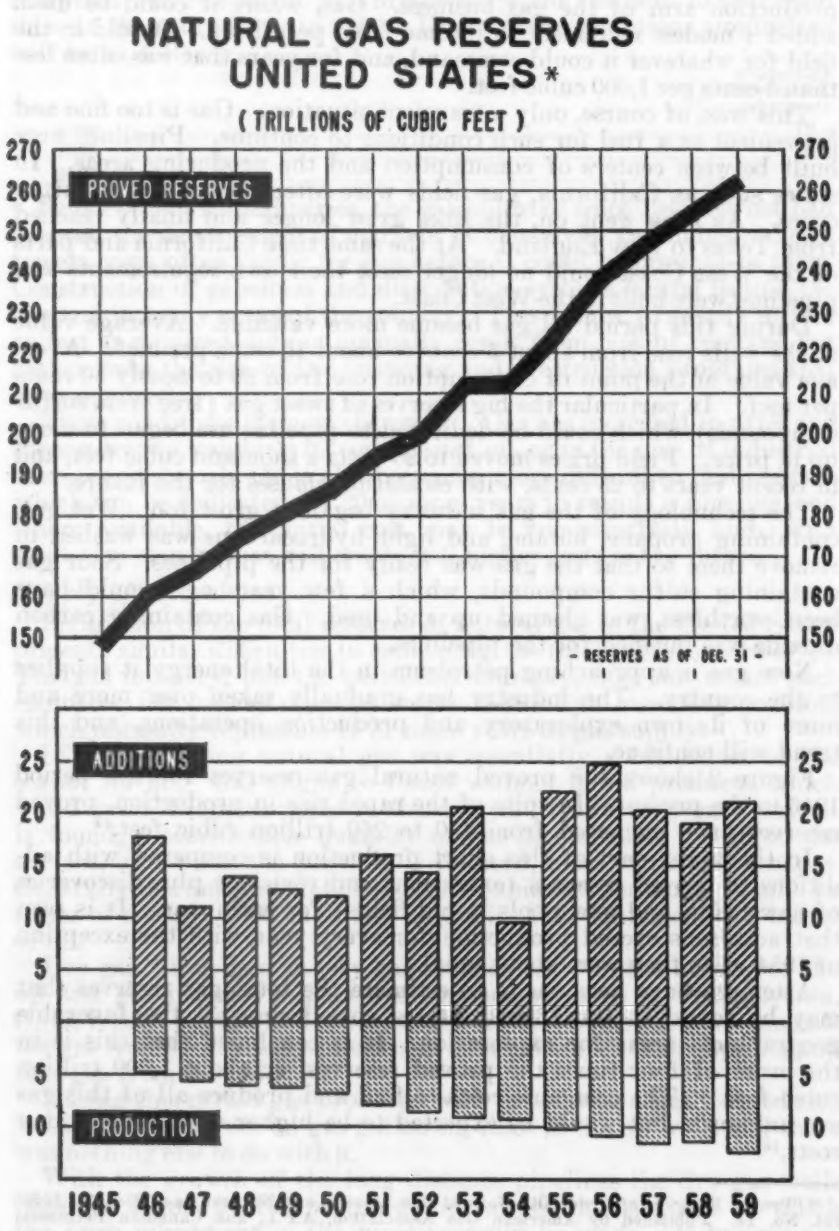
[14] "Proved Reserves of Crude Oil, Natural Gas Liquids, and Natural Gas," Dec. 31, 1959, vol. No. 14. Published by American Gas Association, A.P.I., and Canadian Petroleum Association.

[15] Review Group on the Basis of Industry Interviews.

[16] This is in disagreement with the views expressed by Bruce C. Netschert, December 1959 (Resources for the Future, Inc.).

FIGURE 2



*"Proved Reserves of Crude Oil, Natural Gas Liquids, and Natural Gas," Dec. 31, 1959, vol. No. 14.

During the past 15 years demand has been rising very fast and the ratio of proved reserves to demand has fallen from 32 in 1946 to 22 in 1959. This probably reflects in part the disparity in rates of growth between oil and gas consumption. Since oil consumption has been growing less rapidly than gas, a lower level of exploratory effort has been satisfactory. This again points to the need for the gas industry to conduct its own exploration on a large scale.

Certain other differences between oil and gas must be kept in mind with respect to future requirements. One is that the efficiency of gas removal from the formation is high, running around 80 to 90 percent as compared to oil at less than half this level. This means little chance for "secondary recovery" as practiced in the oil industry. A second is the limited possibilities for importing gas as compared to oil. By tanker oil can be moved half way around the world at low cost. Gas imports to the United States are now limited to Canada and Mexico and this situation cannot be greatly changed in the future. Imports of Canadian gas are growing and very recently the Canadian government authorized exports of 275 billion cubic feet a year from Alberta fields. Later on gas may be imported from Mexico, although such gas is often closest to the areas of the United States which have the largest reserves.

During the past 5 years methods have been developed for converting natural gas to a liquid at low temperature and transporting it in ships like oil. It is then vaporized and used as a gas at the destination. In this case the entire cargo space must be well insulated to prevent excessive loss through vaporization during the ocean crossing. For such use the gas could be obtained from areas like the Middle East or South America, where at present it is nearly a waste product.

For several reasons it is difficult to see that major quantities of such gas will be moved into the United States in the foreseeable future. From the Middle East the logical market would be Europe, not only because of shorter transportation, but because gas commands a high price in Europe. South American and Caribbean gas might be brought to the United States, but the delivered price appears to be too high.

Pipeline gas can be manufactured from coal, oil shale and tar sands. Making gas from these materials is a much more expensive undertaking than making liquid fuels. The basic reason for this is that gas has a much higher hydrogen content than the liquid fuels and the production of hydrogen is one of the most expensive steps in the processes. In addition, where the raw materials are in remote areas, the cost of the transportation of a gaseous product is considerably greater than the cost of transporting a liquid product.

In some processes for making liquid fuels from solid fuels high B.t.u. gas is produced as a byproduct. This type of operation does appear to have economic possibilities at or near present day market prices for liquid and gaseous fuels.

It is anticipated that consumption will continue to increase rapidly during the next 15 years, but not as fast as during the past period. There is no reason to believe that reserves are not adequate to meet requirements to 1975, however, exploration specifically to produce gas will be needed. This is recognized by the industry and this program is well under way.

The adequacy of reserves from 1975 to 2000 is less predictable. It is anticipated that the price of gas will have reached a competitive level with all other fuels, taking into account, of course, factors which make its use particularly convenient. Its growth curve will then approach that for petroleum.

Imports of gas from Canada and perhaps from Mexico will grow during this period.

Electric power from fuels and water

Electric power is generated from two major sources, fossil fuels and water power. In the United States, coal, oil and gas are used to produce about 71.5 percent of the generated electric power and water power the remainder.

Since electric power from fossil fuels is not a primary source of energy, no attempt will be made to analyze its past and future.

Any type of fuel can be used to generate steam, which drives a turbine, which in turn drives an electric generator. The efficiency of this cycle depends on generating steam at the highest possible temperature and pressure that metals and other materials of construction will allow. Year by year pressures have crept up until now steam is generated at 5,000 pounds per square inch and a temperature of 1,200° F. A single boiler will produce 1 to 2 million pounds of steam per hour, and generators with an output of 325,000 kilowatts are not unusual. At the present time the central power stations are approaching the production of a kilowatt-hour of electricity from 8,000 B.t.u. in the form of fossil fuel which represents an overall efficiency of better than 40 percent.

These large furnaces and boilers can be designed to burn coal, oil, or gas, and in fact some do so interchangably. The fuel used is largely dependent on what is available at the lowest price on a heating value basis. In units of this type coal gives a slightly higher thermal efficiency than oil or gas.

Oil and gas can also be used in other prime movers such as Diesel engines, gas driven combustion engines, or in combustion turbines. This equipment is well adapted for smaller power installations, and may be particularly useful in areas where water supply is limited. It is not thermally as efficient as boilers and steam turbines.

Consumption of coal in steam-electric plants has been increasing steadily since the War. Between 1948 and 1958 it rose from 100 to 156 million tons per year. Oil used in such plants increased from 43 to 77 million barrels and gas from 478 to 1,373 billion cubic feet. [17]

In the United States [18] in 1958 the installed capacity for hydropower generation was 30 million kilowatts and the annual generation was 144 billion kilowatt-hours of energy. By 1975 the developed power in the United States will have reached an estimated annual generation of 244 billion kilowatt-hours with installed capacity around 53 million kilowatts. By 2000 annual hydroelectric generation is estimated at 392 billion kilowatt-hours with installed capacity of 87 million kilowatts. This leaves an estimated 180 billion kilowatt-hours of undeveloped hydroelectric energy at that time.

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[17] Data taken from "Petroleum Facts and Figures, 1959."
It should be noted that the fuel required for electric power generation has already been included in the talley for coal, oil, and gas.

[18] Data from report prepared for Joint Committee on Atomic Energy by Federal Power Commission (April 1960).

It should be noted that these values for hydroelectric power represent a net increase in the total available energy output.

CONSUMPTION AND SUPPLY OF ENERGY IN CANADA

Canada and the United States have been the world's largest users of energy on a per capita basis. In many respects the energy consumption and supply of the two countries is following a roughly parallel pattern.

The change [19] in pattern of energy use in Canada between 1929 and 1953 is as follows:

	Percent of total		
	1929	1939	1953
Manufacturing	20	20	24
Transportation	29	27	30
Household commercial	40	42	31
Supplying energy	7	8	10
Other	4	3	5
Total	100	100	100

The pattern of energy supply has changed more sharply than the pattern of use as shown by the following:

Energy source	Percent of total		
	1929	1939	1953
Coal	69	56	39
Petroleum	10	20	42
Natural gas [1]	2	3	4
Wood	16	14	7
Waterpower [2]	3	7	8

[1] Includes natural gas liquids.
[2] Measured in terms of contribution as electricity.

Coal is furnishing a smaller percentage of the total energy and oil and natural gas are growing. Canada is fortunate in having large amounts of available waterpower, and this is making an increasing contribution to the energy supply.

Consumption of coal

The requirements for coal in Canada reached a peak in the 1940's and have been declining sharply since that time. Estimated consumption for each principal end use is as follows:

	In millions of short tons		
	1955	1965	1975
Space heating	8.3	3.0	2.0
Transportation	6.0	1.3	.5
Manufacture and mining	10.5	10.3	12.0
Cokemaking	5.5	8.0	12.0
Electric power	1.8	6.0	22.0–40.0
All other	1.7	1.8	2.0– 8.0
Total consumption	33.8	30.4	50.5–74.0

[19] Throughout this section on Canada the writer has drawn freely on "Canadian Energy Prospects," March 1957, by John Davis. (This is one of the studies made by the Royal Commission, W. L. Gordon, Chairman, on "Canada's Economic Prospects.")

The use of coal for space heating is expected to decrease until 1975 and after this to be used only in areas where coal has a particular price advantage. Transportation will shift essentially completely to oil. In certain manufacturing and mining industries coal use will continue and grow slightly. The use of coke in steel and other metallurgical industries is also expected to grow. So far as electric power is concerned the use of natural gas will grow and that coal consumption for this purpose may not grow beyond the estimates for 1975. Total coal consumption for 1975 is estimated at 50–75 million tons and for 2000 about 100 million tons.

Supply of coal

Canada is thought to have about 2 percent of the world's known coal resources. At the present time this is estimated at 94 billion tons [20] about two-thirds of which can be considered mineable. This will be further reduced by mining losses which leaves about 30 billion tons of recoverable coal.

The reserves are not well distributed, those in eastern Canada amounting to less than 4 percent of the recoverable coal, with 95 or 96 percent found west of Winnipeg. Much of the coal is in Alberta, although British Columbia and Saskatchewan also have some reserves. Even the eastern coals are a considerable distance from centers of use such as Quebec, Montreal, and Ottawa.

The reserves are of good quality, amounting to 15 percent low volatile, 31 percent medium volatile, and 17 percent high volatile bituminous; 9 percent is subbituminous, and 28 percent is lignite. Good coking coals are found.

Mining conditions in the east are not good. All the Nova Scotia coal is underground and the mines are deep. There is some strip mine coal in New Brunswick, but the seams are thin. The western coals can be mined much more easily, but freight rates to centers of use are high.

The cost of mining coal in Canada has generally been higher than in the United States. In order to help meet these differences, some subsidies have been paid to Canadian producers. In spite of this assistance, imports, mostly from the United States, continue to be around 50 or 60 percent of the domestic supply.

Consumption of coal in Canada at the present time is about 34 million tons. This is expected to increase to 50–75 million tons in 1975 and perhaps to 100 million tons in 2000. Canada has ample coal reserves to meet these requirements for centuries. Most of this coal is in the western part of the country and would require a long freight haul to the consuming centers. It is probable that Canada will import half or more of its coal requirements, and will turn increasingly to oil and gas as cheaper and more convenient sources of energy.

Consumption of petroleum

On a worldwide basis, postwar petroleum requirements are growing at the rate of about 6 percent per year. Canadian consumption has grown at the rate of 12 percent, and the country is now one of the

[20] A 1913 estimate set the reserves at 1,200 billion tons, but this included very deep coal in thin seams which has been excluded from the present estimates.

world's largest users of petroleum. On a per capita basis Canadian use is second only to that of the United States.[21]

Consumption of various petroleum products from 1920 to 1960 is as follows:

	Thousands of barrels per day				
	1920	1930	1940	1950	1960 [1]
Gasoline	8	47	68	137	282
Diesel oil and light fuel oil	9	12	20	87	269
Heavy fuel oil	11	27	40	80	131
Lubricating oil	2	3	4	6	9
All other products	6	6	12	31	93
Refinery consumption	3	9	14	26	54
Total	39	104	158	367	838

[1] Estimated by writer.

Consumption in the next 15 years will continue to grow, although it is believed that it will be below the 12-percent rate of the postwar years. The reasons for this are that natural gas will replace oil in many uses, that oil has already displaced coal in most applications where it can be used, and the oil economy is becoming more mature and a lower growth rate is normal. A 5-percent growth rate was taken for the period 1960 to 1975 and 4 percent after this. Under these conditions, total consumption is estimated as follows:

Year:	*Millions of barrels per year*
1960	306
1975	650
2000	1,700

Supply of petroleum [22]

Canada is believed to have been a producer of petroleum for about 100 years, but the amounts were insignificant until 1930. In 1936 Turner Valley became a major oil field and this was followed by discovery of the Leduc field near Edmonton in 1947. Since that time production has risen twentyfold. Proved reserves have risen from 70 million barrels to about 4.6 billion barrels.[23]

The effect of these discoveries has been reflected in Canadian oil imports as follows:

	Thousands of barrels a day					
	1920	1930	1940	1945	1950	1955
Domestic production	22	83	127	164	278	535
Imports	16	23	18	16	75	104
Imports as percent of supply	42	22	12	9	21	16

Imports are still increasing, but as a percentage of the total supply they have dropped from 42 to 16.

[21] See "Canadian Energy Prospects," pp. 127–128.
[22] Much of the data for this section were taken from "Canadian Energy Prospects."
[23] Oil and Gas Journal, Mar. 21, 1960, vol. 58, No. 12, p. 73.

Production of large quantities of oil in western Canada has changed the distribution pattern in both Canada and the United States. This oil is moving into all the western parts of Canada and eastward to the Great Lakes. It will be used to supply Minneapolis, St. Paul, Michigan, Toronto, and Sarnia. It is also moving into the Pacific Northwest and will be used to supply consuming centers in Washington, Oregon, and perhaps other States.

Canadian oil production is in the early and flush period of its growth and appears to be in a very favorable technical and economic position in comparison with United States production. John Davis [24] listed these facts about the two countries:

1. In 1955 one out of every five new field wildcat wells has resulted in an oil find, compared with one in nine in the United States.

2. In 1955 newly discovered resources per exploratory well were 70,000 barrels, compared with 40,000 barrels in the United States.

3. In recent years, reserves discovered per foot of drilling in exploratory wells were approximately double the reserves per foot added by similar drilling in the United States.

4. Discoveries have now been made in many of the major horizons which have been proven productive elsewhere on this continent.

5. There appears good reason to believe that Canada's western provinces may well encompass one of the most prolific oil producing regions in North America.

As a result of these conditions, it is quite possible that the cost of producing Canadian oil in terms of 1960 dollars will hold steady or perhaps go down for the next 15 to 20 years. This is in contrast with costs in the United States which are expected to rise.

In addition to petroleum, western Canada contains large reserves of tar sands, particularly around Lake Athabasca, from which gasoline and other petroleum products can be made. The reserves are reported in the order of 300 billion barrels.

Methods for mining the tar sand, removing or extracting the oil and refining it have been developed, but up to the present time have not been economic in comparison with petroleum. Since mining costs are important in this operation, it is improbable that the whole reserve is recoverable at costs approaching those now applicable and it would be best to consider only the reserves which can be strip mined without removing excessive amounts of overburden. In this case it would seem more realistic to consider 5 or 10 percent of the total reserves as suitable for low-cost mining operations.

At the present time several large oil companies are investigating the methods and economics of utilization of the tar sands and at the completion of this work the economic status may be clarified.

So far as the Canadian oil position is concerned, it may be concluded that consumption will grow during the next 15 years, although not as fast as during the past 15 years. Estimated consumption for 1960 is 306 million barrels and this is expected to rise to 650 million barrels by 1975 and 1,700 million barrels by 2000. It is anticipated that Canada will become more than self sufficient in oil and will go on to become an exporter of oil on a large scale.

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[24] "Canadian Energy Prospects," p. 115.

Consumption of natural gas

Natural gas has become available to large numbers of Canadian consumers so recently that the industry can be considered as only beginning. Marketed production in 1945 was about 40 billion cubic feet, and by 1955 it had risen to 170 billion cubic feet. From this small base any prediction for the future may be greatly in error.

John Davis [25] estimated the increase at 10 percent per annum to 1980 and 4 percent thereafter. This gave annual production as follows:

Year:	*Annual marketed production in trillion cubic feet*
1955	0.17
1959	(1)
1965	.85
1980 [2]	3.0
2000 [2]	5.5

[1] Total production in 1959 was 0.498 billion cubic feet. See Oil and Gas Journal, Mar. 21, 1960, vol. 58, No. 12, p. 73.
[2] This includes an estimated trillion cubic feet annually to the United States.

These estimates include gas for export to the United States. During the early part of 1960 the Canadian Government authorized the export of 6,529 bilion cubic feet of gas from Alberta fields to the United States over periods up to 25 years. The average was about 275 billion cubic feet per year.

It is quite possible that the United States will want and need considerably more gas from Canada in the future than is indicated in these estimates. This question will ultimately be resolved by the availability of the gas and the Canadian requirements.

Supply of natural gas

Proved reserves of natural gas in Canada were estimated at 26 trillion cubic feet at the end of 1959.[26] This was over 50 times production for that year.

Study of Canadian gas requirements, including export, indicates that if it is desired to maintain a 25-year reserve, the amount of gas normally obtained with oil production will not be sufficient. In detail it is concluded: [27]

(1) Without special incentive to look for gas there will be sufficient gas to meet Canada's requirements for the near future.

(2) After 1970, the amount of gas produced with oil (assuming about 5,000 cubic feet of gas per barrel of oil) will be less than required to supply the domestic market.

(3) A volume of gas in excess of 1 trillion cubic feet annually cannot be committed to United States markets without endangering the Canadian position after 1980.

These views may be altered by the future course of discoveries. Particularly, it may be possible to increase gas reserves substantially if there is an incentive to look for gas and to develop it independently of petroleum. In turn this may require a substantially higher price for gas in the field.

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[25] "Canadian Energy Prospects," p. 182.
[26] "Canada's Energy Prospects," pp. 181–182.
[27] Oil and Gas Journal, Mar. 21, 1960, vol. 58, No. 12, p. 73.

Electric power

Approximately 90 percent of Canada's power is hydroelectric. This has led to costs which on the average are the second lowest and per capita consumption which is the second highest in the world. Norway is the only country which surpasses Canada in these respects. In 1953 average costs in Canada were 0.8 cents per KWH and yearly consumption 5,200 KWH per capita.

Total consumption for the country was 81 billion KWH for 1955 and is estimated near 115 billion KWH for 1960. At a growth rate of 7 percent demand for electric power is estimated as follows:

Year:	*Billions of KWH*
1955	81
1960	115
1975	310
2000	1,700

As of January 1956, it was estimated that Canada's waterpower potential was between 22 (minimum flow conditions) and 38 (ordinary flow conditions) million kilowatts. This was based on 80-percent efficiency. The installed turbine capacity at that time was 13,000 KW or 34 percent based on ordinary flow conditions. Only about one-third of the available hydroelectric power is in use and it is believed expansion of this source can continue until the 1970's.

Beyond that time the installation of thermal plants will grow. With low cost coal, oil and gas this offers no problems in western Canada, and in fact, with modern thermal stations, power costs may not even rise appreciably. In eastern Canada where the fuel has to be brought in from the western provinces, or imported, power costs may tend to rise.

CONSUMPTION AND SUPPLY OF ENERGY IN THE CARIBBEAN

The Caribbean area comprises the following countries: Bahama Islands, Barbados, Bermuda, British Honduras, Colombia, Costa Rica, Cuba, Dominican Republic, El Salvador, Guadalupe, Guatemala, Haiti, Honduras, Jamaica, Leeward Islands, Martinque, Mexico, Netherlands Antilles, Nicaragua, Panama Republic, Panama Canal, Puerto Rico, Trinidad, Venezuela, Virgin Islands, and the Windward Islands.

The consumption of solid fuel in the area is negligible, amounting to less than 5 million tons. Practically all of this is consumed and produced in Colombia and Mexico. Total recoverable coal resources for the area are estimated at only 2 billion tons.

The consumption of liquid fuel has been as follows:

Year:	*Millions of barrels*[1]
1955	190
1956	204
1957	234
1958	242

[1] "World Energy Supplies, 1955–1958" (published 1960), United Nations.

Major consuming countries were Colombia, Cuba, Mexico, Netherlands Antilles, Puerto Rico, and Venezuela.

Production in the area was as follows:

Year:	*Millions of barrels* [1]
1955	866
1956	976
1957	1,090
1958	1,040
1959	[2] 1,200

[1] "World Energy Supplies, 1955–1958" (published 1960), United Nations.
[2] Oil and Gas Journal, Jan. 25, 1960, vol. 58, No. 4, p. 174.

Production has been approximately four times consumption and the area is a major exporter of petroleum products. Venezuela is by far the most important country in this respect, although Trinidad, Colombia, and Mexico are also substantial exporters.

Production and proved reserves in five countries in 1959 were as follows:

Country	Millions of barrels [1]	
	Production	Proved reserves
Colombia	53.0	750.0
Cuba	.2	2.6
Mexico	96.0	2,500.0
Trinidad	41.0	425.0
Venezuela	1,010.0	18,000.0
Total	1,200.0	21,678.0

[1] Oil and Gas Journal, Jan. 25, 1960, vol. 58, No. 4, p. 174.

Undiscovered, but potentially recoverable reserves were estimated at 120 billion barrels.[28]

Between 1955 and 1958 consumption in the area increased by about 27 percent. By 1975 it may be anticipated that consumption would be in the order of 600 million barrels, and by 2000 from 1 to 1.5 billion barrels.

It is evident that the area should have ample reserves for its own needs to the year 2000 and be able to export increasing quantities as they can be utilized by the world markets of the future.

The use of natural gas is becoming important in Mexico, and Venezuela, particularly with respect to oil production, and amounted to about 280 billion cubic feet in 1958. The proved reserves are estimated at 40 trillion cubic feet [29] with potential reserves much larger than this. As industrialization grows, undoubtedly larger amounts of gas will be needed in the area. On the other hand, methods are needed to export this gas to other countries to make full use of the gas reserves as well as gas which is now being produced with oil.

CONSUMPTION AND SUPPLY OF ENERGY IN OTHER AMERICAN COUNTRIES

Other American countries, as defined for this report, comprise 12 countries or territories: Argentina, Bolivia, Brazil, British Guiana, Chile, Ecuador, French Guiana, Paraguay, Peru, Surinam, Uruguay.

[28] "Resources of Coal, Petroleum, Natural Gas, Oil Shale, and Tar Sands in the United States and Allied and Neutral Countries," March 1960, Department of the Interior.
[29] "Resources of Coal, Petroleum, Natural Gas, Oil Shale, and Tar Sands, in the United States and Allied and Neutral Countries," March 1960, Department of the Interior.

Coal consumption is small, amounting to 8 million standard tons in 1958. Production was about 5 million standard tons. Brazil and Chile produce nearly equal amounts, amounting to about 90 percent of the total. Argentina and Peru are the only other producers. Argentina and Brazil were the major importers of coal.

It does not seem probable that South America will become a large coal producing area. As the steel industry grows, there will undoubtedly be a growth in coal mining for coke production where suitable coal is available. For energy and transportation, other fuels appear to offer more promise.

The reported resources of coal and lignite in South America are not large, amounting to about 4 billion tons. Of this, only about one billion tons is of probable economic value, with around 500 or 600 million tons as recoverable. Since South America has not been extensively explored, these estimates may, of course, be far too low.

Petroleum consumption in the area has been as follows:

Year:	*Millions of barrels* [1]
1955	175
1956	190
1957	200
1958	213

[1] "World Energy Supplies, 1955–1958" (published 1960), United Nations.

Major consuming countries are Argentina, Brazil, Chile, Peru, and Uruguay. Estimated consumption for 1960 is 220 million barrels and for 1975 it is 540 million barrels and for 2000 it is 1,500.

The area has important and growing oil production, as follows:

Year:	*Millions of barrels* [1]
1955	53
1956	57
1957	65
1958	75
1959	100

[1] "World Energy Supplies, 1955–1958" (published 1960), United Nations.

On balance the area imported oil for each of the years indicated. Argentina, Brazil, Chile and Uruguay were the largest importers. Peru was an exporter.

Production and proved reserves for the various countries in 1959 were as follows:

Country	Millions of barrels [1]	
	Production	Reserves
Argentina	47	2,000
Bolivia	3	94
Brazil	24	250
Chile	6	65
Ecuador	3	24
Peru	17	325
Total	100	2,758

[1] The Oil and Gas Journal, Jan. 25, 1960, vol. 58, No. 4, p. 174.

It is believed that some of these countries will ultimately become large oil producers, and the undiscovered but potentially recoverable petroleum has been estimated at 80 billion barrels.[30]

The use of natural gas in the area has increased from 47 billion cubic feet in 1955 to 78 billion cubic feet in 1958. The major use was in Argentina, although Brazil and Chile used appreciable and growing amounts. Proved reserves of natural gas are indicated as 10 trillion[30] cubic feet and undiscovered potential reserves as 250 trillion cubic feet.

Between 1954 and 1965 it is predicted that the total gross consumption of energy will grow about 75 percent. Practically all of this will be supplied by petroleum and natural gas.

It is evident that as a whole these South American countries have more than enough oil and gas to meet their requirements for the next 40 years. Their resources appear relatively undeveloped, and while many countries are now importers, some of them may ultimately become large-scale exporters.

In addition to petroleum, Brazil is also known to have large resources of oil shale. These are estimated at 300 billion barrels of oil in place.[31] Over the period of the past 20 or 25 years considerable experimental and development work has been done on these shales and mining and processing methods have evolved for their utilization. Cost of producing oil from shale is probably high compared to importing oil, but these economic factors may change in the future.

CONSUMPTION AND SUPPLY OF ENERGY IN O.E.E.C. COUNTRIES

For this report the countries comprising the O.E.E.C. (Organization for European Economic Co-operation) group are: Austria, Belgium, Denmark, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, and the United Kingdom.

In the past these countries have been characterized by having little oil or natural gas. Some of them have no coal, while others have coal which can only be mined at high cost. These conditions have led to high fossil fuel costs in some parts of the O.E.E.C. area. Countries like Norway, Sweden, and Switzerland have hydroelectric power which has made electric energy available at relatively low cost.

In the O.E.E.C.[32] area coal is the dominant fuel. In the larger industrialized nations such as Belgium, France, Germany, Italy, the Netherlands and the United Kingdom coal still furnishes over half the energy. Nevertheless, coal is now beginning to lose its hold as shown by the contribution of the various forms of primary energy between 1938 and 1958.

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[30] "Resources of Coal, Petroleum, Natural Gas, Oil Shale, and Tar Sands in the United States and Allied and Neutral Countries," March 1960, Department of the Interior.

[31] "Resources of Coal, Petroleum, Natural Gas, Oil Shale, and Tar Sands in the United States and Allied and Neutrol Countries," March 1960, Department of the Interior.

[32] Much of the data on the O.E.E.C. area was taken from the report, "Towards a New Energy Pattern in Europe," January 1960, published by the Organization for European Economic Co-operation.

Percentages

Year	Coal and lignite	Oil	Natural gas	Hydro-power	Other forms
1938	85	8	----	4	3
1948	80	10	----	6	4
1949	79	12	----	6	3
1950	77	13	----	7	3
1951	76	14	----	7	3
1952	75	15	----	7	3
1953	73	16	1	7	3
1954	71	18	1	7	3
1955	69	20	1	7	3
1956	68	21	1	7	3
1957	67	22	1	7	3
1958	62	25	1	9	3

Between 1938 and 1958 coal dropped from 85 to 62 percent of the primary energy while oil came up from 8 percent to 25 percent. Hydro power is also rising and is now contributing nearly 9 percent. In 1953 natural gas began to be a contributor to primary energy and, as will be shown later, its use is expected to grow to large proportions.

The basic reason behind these changes are clear. Before the war the whole O.E.E.C. area was dependent on coal. Utilities, industries and homes used coal for heating and power. The disruption of coal production caused by the war, the difficulty of resuming full output after the war, the problem of training reluctant new employees in mining, and the rising prices for coal all created a wide area for another large energy source. After the war the rapid rise in Middle East oil reserves, the ease of finding oil, its low cost production, the growth of the super tanker, all made oil the convenient and low cost fuel to meet O.E.E.C. needs. It has stepped in to fill the gap and there is little doubt this process will continue and probably on an increasing scale for the next few decades.

Consumption and supply of coal

The consumption of coal and lignite in the O.E.E.C. areas for the period 1938–58 compared with indigenous production and imports is as follows:

Millions of short tons equivalent [1]

Year	Consumption	Indigenous production	Approximate imports	Year	Consumption	Indigenous production	Approximate imports
1938	542	548	----	1953	552	549	3
1948	488	462	26	1954	568	555	13
1949	516	502	14	1955	596	558	38
1950	520	513	7	1956	611	564	47
1951	573	540	33	1957	603	566	37
1952	565	553	12	1958	560	555	5

[1] Based on 25,500,000 B.t.u./short ton.

In terms of tons, coal was at peak production from 1955–1957. Both indigenous production and imports were also at their highest levels during these years. For the whole O.E.E.C. area imports did not exceed 8 per cent of consumption for any year.

As noted before the burden of increased energy requirements is being taken by oil, not coal. Coal consumption fell by 51 million tons between 1956 and 1958. Part of this decline resulted from the de-

pression in the steel industry and may be recovered. It is probable, however, that future consumption of coal will depend on producing it at lower and competitive costs.

Coal costs in most of Europe tended to rise rapidly after the war. Competition with oil, however, is forcing a marked change in mining methods, as well as the closing of higher cost mines. During recent years mechanization of the mines has grown and costs are now coming down. It is believed this trend will continue in the future.

Coking coal will hold its markets for the metallurgical industries, but coal for utilities will compete more and more with oil. It is also to be expected that the railroads will convert to oil. Residential consumers will shift to oil and then ultimately to natural gas where it becomes available. This brings up the additional point that a great deal of manufactured gas in Europe is made from coal. In the next 15 to 40 years a good deal of this market will be lost to natural gas transmitted by pipeline or possibly brought in by ship.

In 1958 coal was used in the O.E.E.C. area as follows:

	Millions of short tons	Percent
1. Industry:		
Iron and steel [1]	9.5	1.7
Other	64.5	11.5
2. Transport:		
Railways	29.2	5.2
Ocean bunkers	1.1	0.2
Other	1.9	0.3
3. Other uses	88.2	15.6
4. Transformation into other forms including electricity and gas	349.0	62.0
5. Fuel used in energy production	20.0	3.5
Total	563.4	100.0

[1] Does not include coal for carbonization.

The production of hard coal in the O.E.E.C. area reached a peak between 1913 and 1929 and has fallen slowly since that time as shown by the following:

Production of hard coal (anthracite and bituminous)

Year	Millions of short tons	Year	Millions of short tons
1900	395	1952	522
1913	543	1953	519
1929	551	1954	522
1937	536	1955	525
1949	475	1956	529
1950	485	1957	530
1951	510	1958	519

In 1958 production was 519 million short tons. It is not believed that production will increase much over this level by 1975.

Lignite production is largely in western Europe. Output has risen from 13 million tons in 1900 to 59 million tons in 1925 and to 120 million tons in 1958. These values are on the basis of actual tons not equivalent tons.

Much of this lignite is strip mined and good progress has been made in the development of large efficient mining methods and machinery. The Federal Republic of Germany accounts for 90 percent of the production and 75 percent of the reserves.

The future programs for Germany, Greece, Turkey, Italy, and other countries provide for increased use of lignite, for electric power generation, domestic fuel and for the production of chemicals. Estimated production to 1975 is as follows:

	1955	1965	1975
Lignite (millions of short tons)	115	165	220
Millions of short tons of coal equivalent [1]	33	50	66

[1] 25,500,000 B.t.u. per short ton coal equivalent.

In terms of actual quantity of energy these figures are small, but they are important to individual nations.

Estimated remaining resources of anthracite and bituminous coal in western Europe and Turkey are about 460 billion short tons.[33] Resources of economic interest are indicated as 220 and recoverable resources at 150 billion short tons. At a production rate of 500 million tons a year, the reserves are ample. It is also clear that coal mining activities are not going to be governed by the availability of reserves, but by the cost of mining in comparison with the cost of competitive fuels.

Total reserves of lignite and brown coal in western Europe and Turkey are estimated at 85 billion tons, with resources of probable economic value near this same level. Since a considerable amount of the reserves may be strip mined, ultimate recovery probably will be around 70 percent, which would indicate recoverable lignite around 60 billion tons. At estimated 1975 production rate of 220 million tons it is evident that reserves are sufficient for a long time. Because of the comparatively low mining costs for this material, it will undoubtedly be an important energy source for some of the O.E.E.C. countries for 40 years and more.

Consumption and supply of petroleum

The consumption of oil in O.E.E.C. countries did not become of major importance until after World War II as shown by the following:

Year:	*Millions of barrels* [1]	Year—Continued	*Millions of barrels* [1]
1938	230	1953	570
1948	291	1954	666
1949	340	1955	767
1950	402	1956	883
1951	486	1957	885
1952	520	1958	1030

[1] Based on 7.2 bbls. of oil per metric ton. (See "Towards a New Energy Pattern in Europe," p. 16.)

Consumption in 1948 was only slightly higher than at the beginning of the war. By 1953 it was about double the 1948 figure and in 1958 it reached 1,000 million barrels.

[33] "Resources of Coal, Petroleum, Natural Gas, Oil Shale, and Tar Sands in the United States and Allied Neutral Countries." March 1960, Department of the Interior Report.

The total consumption of oil, indigenous production, approximate imports, and percent indigenous production are as follows:

Millions of barrels [1]

Year	Consumption	Indigenous production	Approximate imports	Percent indigenous consumption
1938	230	5	225	2.2
1948	291	15	276	5.2
1949	340	19	321	5.6
1950	402	25	377	6.2
1951	486	33	453	6.8
1952	520	41	479	7.9
1953	570	47	523	8.2
1954	666	55	611	8.3
1955	767	64	703	8.4
1956	883	72	811	8.2
1957	885	84	801	9.5
1958	1,030	88	942	8.5

[1] See A New Energy Pattern for Europe, pp. 16 and 18.

It is seen that imports supplied 90 percent of the oil or more. However, the fact that indigenous production was able to expand with consumption, and between 1948 and 1957 actually supplied an increasing percentage of oil is very significant. Increasing production attests to the fact that commercial quantities of oil are available in the O.E.E.C. countries and that vigorous exploration is justified.

Oil was utilized in 1958 in O.E.E.C. countries as follows:

	Millions of barrels	Percent
Industry:		
Iron and steel	34	3.3
Other	190	19.0
Transport:		
Railway	17	1.6
Ocean bunkers	96	9.5
Other	283	28.0
Other uses	205	20.4
For transformation including production of electric power and gas	123	12.0
Consumed in the oil industry	62	6.2
Total	[1] 1,010	100.0

[1] Not directly comparable with previous table because of stock changes.

The estimate of crude oil consumption and supply for the period 1955 to 1975 is as follows: [34]

Millions of barrels [1]

	1955	1965	1975	2000
Indigenous supplies	64	150	250	
Imported supplies [2]	720	1,300–1,550	1,900–2,500	5,000–7,000

[1] Estimated on the basis of 5 barrels per metric ton of coal equivalent.
[2] Taking account of variations in stocks.

[34] "Towards a New Energy Pattern in Europe," p. 96.

This table indicates that consumption will about double between 1955 and 1965 and will then increase by approximately 50 percent between 1965 and 1975. The uncertainty becomes much greater between 1975 and 2000, but the writer believes the growth rate will be slower and has estimated on the basis of 4 percent per year compounded. This indicates consumption around 5,000–7,000 million barrels.

It is expected that indigenuos supplies will about double between 1955 and 1965 and increase substantially again by 1975. Predictions for indigenous supplies are very uncertain. The writer believes that with an intensive drilling and exploration campaign these estimates could be exceeded. On the other hand, much of this oil may be expected to cost more to find and produce than oil in the Middle East. Therefore, the magnitude of indigenous production will depend to a considerable extent on restricting oil imports, either on the basis of volume, or by the application of tariffs.

Thought must also be given as to what such restrictions will accomplish. By 1975 indigenous production will be around 10 percent of the total. While this would help, it would not be enough to support the O.E.E.C. area if all imports were cut off. By the year 2000 indigenous production will probably be considerably less than 10 percent of the total.

Tariffs on imported oil will offer substantial and growing income to the Government. On the other hand, they restrict energy applications and hobble economic growth. The most prosperous nations appear to be those with the greatest use of energy per capita. This condition is encouraged by keeping primary energy sources at the lowest possible cost.

Because indigenous production is so heavily influenced by these economic and political factors, it does not seem possible to extend the estimate beyond 1975.

At the present time the proved reserves in the O.E.E.C. countries are estimated at 1.6 billion barrels [35] and the ratio of reserves to production is 18 to 1. Undiscovered but potentially recoverable hydrocarbon liquids are estimated at 18 billion barrels [35] and if 50 percent of these are discovered by 1975 they could readily support the estimated production at that time. The writer believes, however, that what happens to indigenous production after 1975 is a question of economics and political considerations rather than a question of reserves.

Imported oil is the major source of supply for the O.E.E.C. area. In 1958 the primary sources were as follows:

Imports into O.E.E.C. from—	*Percent of total imported oil* [1]
Middle East	85.2
Caribbean America	11.4
Africa	.8
Far East	.4
Other countries	2.2
Total	100.0

[1] Based on data from "World Energy Supplies, 1955–58" (United Nations).

The Middle East is supplying 85 per cent of the total imported oil.

[35] "Resources of Coal, Petroleum, Natural Gas, Oil Shale and Tar Sands in the United States and Allied and Neutral Countries," Mar. 1960, Department of the Interior.

O.E.E.C supply is contingent on oil from abroad, and this will be discussed particularly in connection with the Middle East and Africa. It may be noted at this time, however, that reserves in these areas appear ample to meet requirements for 1975 as well as the year 2000.

Consumption and supply of natural gas

Much of the O.E.E.C. area has a long history of using gas manufactured from coal or coke. A variety of well known processes have been used to convert solid fuels to gas, including coke ovens, and water gas machines. Some more modern equipment has also been developed, which depends on the use of relatively pure oxygen to permit continuous production and high throughput from a single unit of equipment. Gas produced from solid fuels is often enriched with hydrocarbon gas produced from cracking oil to increase the heating value. In general manufactured gas is marketed in the range from about 450 to 60 B.t.u. per cubic foot, which is about half of the heating value for most natural gas.

Plants manufacturing gas from solid fuels are expensive to build and operate. This, coupled with relatively high cost coal or coke in much of the O.E.E.C. area, often makes the final product high in cost.

In the United States manufactured gas was essentially driven off the market by natural gas and it would appear that this same situation may develop in Europe.

Estimates of consumption for the area are as follows: [36]

Year:	*Billions of cubic feet (1,000 B.t.u. per cubic foot)*
1955	1,100
1965	1,670
1975	2,700–4,400
2000	6,000–10,000

Since natural gas is only now becoming available in quantity to the O.E.E.C. area the industry is in its infancy. A projection of consumption to 1975 may be widely in error. A great deal depends on the political and economic climate in which the industry tries to develop in the O.E.E.C. area, as well as the stability and cooperativeness of the area around the Mediterranean that will supply and transmit the gas. Natural gas pipelines, or shipment of liquified natural gas by tanker demand heavy investments. Such an industry can only thrive with the continuous delivery of large volumes of gas over a long periods of years. Projections to 2000 can be little more than a guess made on the assumption that there will be a strong tendency toward cooperation to make the best use of all available gas supplies.

Before the War natural gas production in Europe amounted to somewhat under 2 billion cubic feet per year. In 1946 it was 14 billion and by 1958 it reached 270 billion cubic feet. This is about a twentyfold increase over the 12-year period prior to 1958. Further very important discoveries have been made in the past two years which will ultimately allow increased production.

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[36] "Towards a New Energy Pattern in Europe," p. 38.

In 1958 it was stated: [37]

> The recent geological survey of O.E.E.C. countries, made under the aegis of the Oil Committee, clearly indicates that geological conditions in many member countries give good prospects for finding new reserves of crude oil and natural gas and we believe that it can reasonably be expected that available reserves of natural gas will be raised by 1975 to several times the amount so far proved.

Production of natural gas, in comparison with consumption of both manufactured and natural gas in O.E.E.C. area is as follows:

Year	Billions of cubic feet [1]		
	Production of natural gas (1,000 B.t.u. per cubic foot)	Consumption of natural and manufactured gas (1,000 B.t.u. per cubic foot)	Percent production consumption
1955	180	1,100	16
1965	700	1,670	42
1975	1,400–1,600	2,700–4,400	32–60

[1] "Towards a New Energy Pattern in Europe," pp. 45–46.

The proved reserves of natural gas are now estimated at 5 trillion cubic feet.[38] On the basis of a 1960 consumption of 360 billion cubic feet the ratio of reserves to production is 14 to 1. The undiscovered but potentially recoverable reserves are estimated at 50 trillion cubic feet. If 50 percent of this is found by 1975 it would provide a suitable reserve for the 1975 production. These estimates after 1975 are subject to great doubt and economic considerations may alter the picture materially.

Referring again to the estimates for the production of natural gas, it is anticipated that it will rise much more rapidly than consumption and that in 1965 indigenous natural gas production will be 42 percent of the total of natural and manufactured gas used. After 1965 consumption will increase sharply and production may be pressed to keep up with it. Beyond 1975 it is believed that with a vigorous gas and oil exploration program production can be kept around one-third of consumption.

At the present time manufactured gas largely makes up the difference between indigenous production and consumption. It is believed that this situation will alter in the future and that gas will be brought to Europe by pipeline or tanker shipment from various areas of the Middle East. Natural gas associated with oil is now going to waste and O.E.E.C. areas offer a logical outlet for this source of energy. As will be shown later, reserves are ample to meet O.E.E.C. requirements to 2000 and beyond.

Electric power

Consumption of electric power in the O.E.E.C. area since 1938 has been as follows:

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[37] "Towards a New Energy Pattern in Europe," pp. 45, 46.

[38] "Resources of Coal, Petroleum, Natural Gas, Oil Shale, and Tar Sands in the United States and Allied Neutral Countries," March 1960, Department of the Interior.

Year	Billions of kilowatt-hours [1]		Percent hydropower	Year	Billions of kilowatt-hours [1]		Percent hydropower
	Consumption	Hydropower net electricity production			Consumption	Hydropower net electricity production	
1938	141	60	43	1953	300	121	40
1948	200	85	43	1954	318	132	41
1949	213	82	39	1955	358	140	39
1950	239	99	41	1956	386	147	39
1951	268	113	42	1957	409	152	37
1952	284	120	42	1958	434	173	40

[1] "Towards a New Energy Pattern in Europe," pp. 16 and 119.

The values for net hydroelectric production show that about 40 percent of the power requirement are supplied by this means. Hydropower represents, of course, a direct addition to the primary energy sources of the O.E.E.C. area.

Electric power production is growing rapidly in the whole area and more than doubled in the 10 years between 1948 and 1958.

Predictions for power production for the future are as follows: [39]

Year	Billions of kilowatt-hours		Percent hydropower
	Consumption	Hydropower net electricity production	
1955	358	140	39
1965	700	240	34
1975	1,200	350	29
2000	3,200	470	15

The growth rates are 7 percent compounded yearly between 1955 and 1965; 5½ percent between 1965 and 1975, and 4 percent between 1975 and 2000.

Hydroelectric production will grow but not as rapidly as total consumption. The estimated growth was at rate of about 5½ percent from 1955 to 1965, and less than 4 percent for the next 10 years. In 1955 only about one-fourth of the potential waterpower had been used. It is estimated that nearly two-thirds of the economically workable hydropotential of Western Europe will be exploited by 1975, and 90 percent by 2000.

CONSUMPTION AND SUPPLY OF OIL (MIDDLE EAST)

The countries in the Middle East group which produce little or no oil are Aden, British Somaliland, Cyprus, Ethiopia, French Somaliland, Israel, Jordan, Lebanon, Libya, Sudan, Somalia, and Syria. Egypt produces small amounts of oil. The major oil-producing countries are Barhein, Iran, Iraq, Kuwait, Qatar, Saudi Arabia. Oil production has grown from approximately 1,000 million barrels in 1955 to 1,700 million barrels in 1959. Consumption of oil is small and is

[39] "Towards a New Energy Pattern in Europe," p. 38.

less than 10 percent of production. Much of this is used in the oil industry itself.

The bulk of Middle East oil goes to the O.E.E.C. countries. Substantial but much smaller amounts go to Japan, Australia, Africa, South America, and other areas.

The proved reserves of petroleum have been growing rapidly in the Middle East since the end of the war and are now far greater than any other area in the world. At the end of 1959 production and proved reserves as reported for individual countries were as follows:

Country	Millions of barrels [1]	
	Production	Reserves
Egypt	21.0	500
Bahrein	17.0	225
Iran	335.0	35,000
Iraq	310.0	25,000
Israel	.7	40
Kuwait	515.0	62,000
Neutral Zone	43.0	6,500
Qatar	63.0	2,500
Saudi Arabia	395.0	50,000
Southern Arabia		100
Syria		1
Total	1,700	181,866

[1] Oil and Gas Journal, Jan. 25, 1960, vol. 58, p. 174.

These reserves are undoubtedly conservative and represent oil already proved by drilling which is recoverable by methods currently in use and under current economic conditions. Allowing for some extension of the fields and improvement in technology, it is believed that a reasonable estimate for recoverable reserves is about 240 billion barrels.[40]

In addition to these proved reserves, an attempt has been made to estimate undiscovered petroleum and this has been estimated at 560 billion barrels.[41]

Estimated imported oil for the O.E.E.C. countries for 1975 ranged from 1,800 to 2,400 million barrels. About 60 percent of the Middle East oil which is exported goes to O.E.E.C., indicating that present reserves are good for well beyond 1975. It is clear also that much more oil will be found in the Middle East and there can be no doubt that supplies are ample to supply foreseeable needs to the year 2000.

Natural gas in the Middle East

At the present time natural gas produced with oil in the Middle East is used by the petroleum industry, but has little other application. In 1956 it was estimated [42] that proved reserves were about 62 trillion cubic feet. Reserves at that time were very poorly defined and it is now believed that this was far too low and that reserves are in the order of 230 trillion cubic feet, most of which will be produced with oil. Undiscovered but potentially recoverable natural gas reserves have been estimated at 2,000 trillion cubic feet.[43]

It is evident that the world must and will develop uses for this tremendous and valuable energy reserve. Two methods are available now for moving the gas to consuming centers. Pipeline transmission probably is the cheapest and could reach Turkey, Greece, Bulgaria, Yugoslavia, Italy and perhaps other parts of Europe. The actual construction of pipelines would necessitate settling the political problems and establishing rights-of-way through a series of inde-

[40] Estimate prepared by task force on the basis of industry interviews.
[41] Resources of "Coal, Petroleum, Natural Gas, Oil Shale, and Tar Sands in the United States and Allied and Neutral Countries," March 1960, Department of the Interior.
[42] Estimate prepared by task force on the basis of industry interviews.
[43] Resources of "Coal, Petroleum, Natural Gas, Oil Shale, and Tar Sands in the United States and Allied and Neutral Countries," March 1960, Department of the Interior. (Note that the Department of the Interior estimates present proved reserves at only 10 trillion cubic feet. This is based on the strict definition of proved reserves as those recoverable under existing technologic and economic conditions.)

pendent countries. In addition, along the entire route the political climate must be stable enough for a long period into the future to justify the heavy capital investment required. Although oil pipelines are operating across a number of these countries, it may be a considerable time before the problems can be solved for the long distance gas lines.

A more immediate solution may be to liquify the natural gas and transport it to Europe by special tanker ships. The technology for this operation appears to be approaching the point of commercial application. The overall cost for transporting the gas by ship is now higher than by pipeline, but it avoids many of the problems connected with construction and operation of the pipelines.

Natural gas can be used to make oil and gasolines. It does not appear that the processes known today could compete with the production of these same products from the low cost petroleum in the Middle East.

CONSUMPTION AND SUPPLY OF ENERGY IN AFRICA

Africa comprises 22 countries or territories, Algeria, Belgian Congo, British East Africa, Rhodesia Nyas, French Cameroons, Equatorial Africa, French Togoland, West Central Africa, Gambia, Ghana, Liberia, Malagasy Republic, Mauritius, Morocco, Nigeria, Angola, Cape Verde, Mozambique Reunion, Sierra Leone, Tunisia, Union of South Africa. About half had an appreciable energy production from fossil fuels in 1958. Total energy production has gone from about 42 million short tons of coal equivalent in 1955 to 50 million short tons in 1958.

Coal and lignite are produced in Algeria, Belgian Congo, Rhodesia, Nyas, Morocco, Nigeria, Mozambique and the Union of South Africa. Total production and consumption for Africa was about 50 million short tons in 1958. The largest coal reserves are in the southern part of Africa. Total resources for the whole continent are estimated at 80 billion tons, with about half of this probable economic value by 2000. Of this amount around 20 billion tons are estimated as recoverable.[44]

Petroleum consumption in Africa was 65 million barrels in 1958 and was increasing slowly. Consumption was estimated at 70 million barrels in 1960, 150 million by 1975, and 500 million by 2000.

Petroleum production in Africa has been small but is increasing. In 1955 the total amounted to about 1.3 million barrels and this had grown to about 8.2 million barrels by 1958. The countries producing oil in 1958 were Algeria, Equatorial Africa, Morocco, Nigeria, Angola and the Union of South Africa.[45]

For 1959 [46] production and reserves in Africa were indicated as follows:

Country	Millions of barrels	
	Production	Reserves
Algeria (including Sahara)	7.8	5,000
Angola	.3	25
Libya		1,500
Morocco	.7	9
Moyen Congo		10
Nigeria	4.0	80
Total	12.8	6,624

NOTE.—Egypt included with Middle East.

[44] "Resources of Coal, Petroleum, Natural Gas, Oil Shale and Tar Sands in the United States and Allied and Neutral Nations, 1960." Department of the Interior.
[45] Production from plant making oil from coal.
[46] Oil and Gas Journal, January 25, 1960, vol. 58, No. 4, p. 174.

Production in 1959 had gone up about 50 percent compared to 1958. Reserves are very large and are growing rapidly. It is now anticipated that the Sahara will eventually be one of the large oil producing areas of the world.

Undiscovered recoverable petroleum has been estimated at about 90 billion barrels, most of which is in North Africa.[47] This estimate can be looked upon only as an approximation.

Natural gas production is very small, but this energy source will be developed as industrial activity grows. At the present time the proved reserves are estimated at 5 trillion cubic feet with undiscovered potentially recoverable reserves at about 250 trillion cubic feet.[47]

In 1958 only a small production of hydroelectric power was reported and this was largely in Algeria, Belgian Congo, British East Africa, Rhodesia Nyas, French Cameroons, and Morocco. Potential hydropower resources of Africa are considerable and will be developed with the economic growth of this continent.

On the basis of data now available, it is not possible to project energy consumption for Africa. Consumption will undoubtedly grow sharply to 1975 and possibly expansion will be even more rapid after that. African resources of coal, oil, and gas will meet these needs without difficulty. It is anticipated that Africa will export oil in increasing quantities to the end of the century. The reserves in Northern Africa will become of increasing importance in supplying Europe with oil. Natural gas will also be used and exported, and it would appear that eventually it could be carried by pipeline to Europe.

CONSUMPTION AND SUPPLY OF ENERGY IN THE FAR EAST

The Far East area is made up of a group of 21 countries or territories: Afghanistan, Brunei, Burma, Ceylon, Cambodia, Taiwan, Hong Kong, India, Indonesia, Japan, Korea, Laos, Macao, Malaya, Netherlands New Guinea, North Borneo, Pakistan, Philippines, Sarawak, Thailand, and Viet Nam. Coal and lignite consumption has been as follows:

Year:	*Millions of tons* [1]
1955	100
1956	110
1957	120
1958	120

[1] "World Energy Supplies 1955–58" (published 1960) United Nations.

The major producers and users of coal were Taiwan, India, Japan, Korea and Pakistan. Taiwan and India produce about as much coal as they consume, while Japan and Pakistan are net importers.

Reserves of coal for the whole area are estimated at about 80 billion short tons.[48] Much of this appears too expensive to mine and reserves of probable economic interest are estimated at only 10 billion tons with about half of this as recoverable coal. This is a very small reserve to support the indicated consumption and they would be used in about 40 years at the present rate of consumption unless more

[47] "Resources of Coal, Petroleum, Natural Gas, Oil Shale and Tar Sands in the United States and Allied and Neutral Countries, March 1960," Department of the Interior.

[48] "Resources of Coal, Petroleum, Natural Gas, Oil Shale, and Tar Sands in the United States and Allied and Neutral Countries" March 1960, Department of the Interior.

can be found. It would appear, therefore, that these countries will encounter higher mining costs in the future and that the coal imports will increase. Also, they will tend to confine their use of coal to making coke or other applications requiring a solid fuel. For heating and transportation the area will turn more and more to oil and gas.

Aggregate oil consumption for the whole area was as follows:

Year:	*Millions of barrels* [1]
1955	185
1956	209
1957	235
1958	248
1959	[2] 178

[1] "World Energy Supplies 1955–58" (published 1960) United Nations.
[2] Oil and Gas Journal, Jan. 25, 1960, vol. 58, No. 4, p. 174.

Major consuming countries were India, Indonesia, Japan, Malaya, Pakistan, Philippines, and Thailland.

Production of oil in the Far East was as follows:

Year:	*Millions of barrels* [1]
1955	119
1956	127
1957	145
1958	[2] 178

[1] "World Energy Supplies 1955–58" (published 1960) United Nations.
[2] Oil and Gas Journal, Jan. 25, 1960, vol. 58, No. 4, p. 174.

On the whole, the area is an importing area and the major importers are Taiwan, India, Japan, Malaya, Pakistan, Philippines and Thailand. Indonesia is the major exporter.

Production and reserves for the important countries of the Far East in 1959 were as follows:

Country	Millions of barrels [1]	
	Production	Reserves
British Borneo (North)	41	500
Burma	4	45
India	3	525
Indonesia	123	9,000
Japan	3	50
New Guinea	2	28
Pakistan	2	25
Total	178	10,173

[1] Oil and Gas Journal, Jan. 25, 1960, vol. 58, No. 4, p. 174.

So far as the future is concerned, it is exceedingly difficult to estimate consumption. Between 1955 and 1958 it rose from 185 to 248 million barrels per year, which is at the rate of about 8 percent compounded annually. The use of oil in these countries is just beginning and this base is too small for any long range projections into the future. Another factor that must be considered is that several of these countries such as India, Japan, and Indonesia, have enormous populations and once their industrialization is under way they may grow rapidly for a long time and this could create a very large demand. Under these circumstances it appeared that a growth of 8 percent com-

pounded annually to 1975 and 6 percent to 2000 was reasonable. This gives consumption as follows:

Year:	*Millions of barrels* [1]
1958	248
1975	920
2000	4,000

[1] "World Energy Supplies, 1955–58" (published 1960), United Nations.

Proved reserves for the area were 10 billion barrels in 1959. Much of this territory has not been well explored and it is probable that a great deal of oil will be found eventually. Undiscovered but potentially recoverable petroleum is estimated at 70 billion barrels.[49] With a strong exploration and development program, this area should become self-sufficient in oil, even though consumption rises at a rapid rate, and it should be able to maintain itself to 1975, and perhaps well beyond.

The consumption and production of natural gas in the area is small and is confined mainly to Indonesia. Japan, Taiwan, Pakistan, and Sarawak produce and use small amounts.

As the petroleum industry develops, the production and consumption of natural gas will also develop and this will become an important contributor to overall primary energy.

CONSUMPTION AND SUPPLY OF ENERGY IN AUSTRALIA AND NEW ZEALAND

Coal consumption for Australia and New Zealand since 1955 have been as follows:

Year	Millions of short tons [1]	
	Australia	New Zealand
1955	25	1.6
1956	25	1.6
1957	25	1.6
1958	26	1.6

[1] "World Energy Supplies, 1955–58" (1960), United Nations.

Production in each country was about equal to consumption.

Total resources of the better grades of coal are estimated at 20 billion tons and lignite and brown coal at 45 billion tons. Resources of probable economic value, however, are estimated at only 6 billion and 8 billion tons respectively. Of these, probably not more than half are recoverable. Present resources appear sufficient to support mining operations to the end of the century.

[49] "Resources of Coal, Petroleum, Natural Gas, Oil Shale, and Tar Sands in the United States and Allied and Neutral Countries," March 1960, Department of the Interior.

Petroleum consumption has been as follows:

Year	Millions of barrels [1]	
	Australia	New Zealand
1955	42	10
1956	52	10
1957	53	11
1958	59	11

[1] "World Energy Supplies, 1955–58" (published 1960), United Nations.

Consumption has been growing slowly in Australia, but only slightly in New Zealand. Neither country produced any oil and amounts indicated above were imported. Petroleum reserves were not reported prior to 1959 although for that year the Oil and Gas Journal (Jan. 25, 1960, p. 174) reported proved reserves at one million barrels for Australia.

Australia at one time produced oil from oil shale but that industry is no longer in existence. Some oil shale reserves are still available. It does not seem likely that the combined consumption in Australia and New Zealand will rise above a few hundred million barrels annually by the end of the century, and this will be imported.

Natural gas is neither produced or consumed in either country.

CONSUMPTION AND SUPPLY OF ENERGY IN THE SOVIET UNION AND EUROPEAN SATELLITES

The availability and quality of data from the Soviet Union and Satellite countries vary widely from country to country. In comparison with the statistical information in the Free World, energy data are fragmentary and uncertain. As a result, it is only possible to highlight some of the major aspects of the energy picture and to generalize about some features of the energy balance through the remainder of the century.

Available data for 1958 and estimates for 1965 indicate an energy output as follows: [50]

Commodity	1958		1965	
	Output	Percent of total output [1]	Output	Percent of total output
Coal and peat (millions of short tons) [2]	424	61.3	513	44.4
Petroleum (millions of barrels) [3]	800	25.7	1,700	32.7
Natural gas (billions of cubic feet)	993	5.4	5,240	17.0
Fuel wood (millions of short tons) [2]	27	4.0	28	2.4
Combustible shale (millions of short tons) [2]	5	.7	8	.7
Hydroelectricity (billions of kilowatt-hours)	40	2.9	74	2.8
Total		100.0		100.0

[1] Based on conversion to energy units.
[2] Based on a standard short ton.
[3] Based on 5,900,000 B.t.u. per barrel.

[50] This table and other data in this section are drawn from a memorandum prepared by the review staff.

Coal is the dominant fuel now and the estimates for 1965 indicate that it will still furnish 44 percent of the energy at that time. The use of petroleum will more than double in the seven-year period. Natural gas utilization is visualized as growing at tremendous speed. The goals reported for the Soviet Seven Year Plan, 1959–1965, indicate that petroleum and natural gas are to be developed at the expense of coal. Based on the information now available, it is believed that oil will pass coal by 1975 in total energy supplied.

Estimated production of coal and peat for the Soviet Union and European satellites is as follows:

Year	Millions of standard short tons [1]	
	U.S.S.R.	European satellites
1959	465	250
1975	620	380
2000	670	460

[1] 25,000,000 B.t.u.'s per ton.

The estimated reserves of coal and peat for the same years are estimated as follows:

Year	Billions of standard short tons	
	U.S.S.R.	European satellites
1959	7,700	39
1975	7,500	39
2000	7,300	37

The high reserves of coal in the Soviet Union are, of course, ample to support estimated production for much longer than 40 years. It should be noted, however, that only about 3½ percent of the reserve is classified as proved, about 12 percent as probable, and the rest as possible reserves. The ratios will, of course, change during the 1959–2000 period with increases in the proved and probable categories and a decline in possible reserves. The writer is inclined to believe, however, that like the coal reserves in the United States, very much of the coal in the possible reserve category will be too deep and too thin to mine. From this standpoint, the recoverable reserves are much smaller than indicated. In any event, the Soviet Union has reserves which are more than ample to support production to the end of the century.

Reserves in the European satellites are not large and over the next 40 year period they will be taxed to meet the anticipated production. This may lead to mining under increasingly adverse conditions with rising costs. It may, therefore, be desirable to ship coal from the U.S.S.R. to the satellites or to substitute oil or gas for coal.

The estimated production of petroleum is as follows:

Year	Millions of barrels [1]	
	U.S.S.R.	European satellites
1959	1,000	100
1975	3,500	150
2000	7,200	200

[1] Estimated on the basis of 7.2 barrels per metric ton.

The above estimates indicate the desire to increase petroleum utilization and production in the U.S.S.R. at a very high rate during the next 40 years.

The reserve picture for petroleum is as follows:

Year	Billions of barrels [1]	
	U.S.S.R.	European satellites
1959	30	1.5
1975	70	2.3
2000	110	2.3

[1] Estimated on the basis of 7.2 barrels per metric ton.

In the U.S.S.R. at the present time proved reserves are about 30 times production. This ratio is expected to decrease in the future, and ultimately to maintain a ratio of about 15 to 1. It seems reasonable to believe that the reserves indicated for 1975 and 2000 can be established in the large geographic area of the U.S.S.R., but it will demand a vigorous exploration and drilling program.

In the satellite countries increase in production is visualized as being much slower. Proved reserves are estimated to increase to 1975 and to remain about constant thereafter. The ratio of reserves to production is 14 to 1 now and this is expected to decrease after 1975. The satellite demand for petroleum would be expected to increase faster than production. Presumably this difference will be made up by imports, and a large share of these probably will come from U.S.S.R.

Estimates for natural gas utilization are as follows:

Year	Billions of cubic feet	
	U.S.S.R.	European satellites
1959	[1] 1,330	350
1975	14,000	800
2000	35,000	1,100

[1] Apparently includes manufactured gas.

These estimates call for a tremendous expansion of natural gas utilization in the U.S.S.R. by 1975 and even thereafter expansion is rapid. Growth in the satellite nations is visualized as considerably slower.

The reserves to support this production are indicated as follows:

Year	Trillions of cubic feet	
	U.S.S.R.[1]	European satellites
1959	53	3
1975	280	3
2000	700	3

[1] Indicated as nonassociated gas only.

So far as the U.S.S.R. is concerned, the reserves appear satisfactory to maintain production. In 1959 the ratio of reserves to production was about 40 to 1; this will drop to 20 to 1 by 1975 and it is expected to maintain this ratio until 2000. A strong drilling program will be necessary to develop these reserves. If gas associated with oil is also considered, the reserves do appear well in line with predicted petroleum production.

For the satellites the ratio of reserves to production is about 8 to 1 now, but by 1975 the ratio is estimated at only 4 to 1 and it will be less by 2000. These reserves are not enough to support the production indicated. Judging from the amount of oil produced, it would appear that the satellite countries could produce the gas indicated along with the oil.

Considering the U.S.S.R. and the satellite countries together, it should be possible to develop gas reserves to meet the complete requirements to the end of the century.

Hydroelectric production is indicated as follows:

Year	Billions of kilowatt-hours	
	U.S.S.R.	European satellites
1959	47	5
1975	320	31
2000	2,700	40

To 1975 growth in both the U.S.S.R. and the satellites is expected to be very fast. After 1975 the U.S.S.R. is viewed as growing more rapidly than the satellites.

The hydroelectric potential for the U.S.S.R. is estimated at 1,200 billion kilowatt-hours. The production projected for 1975 is only about one-fourth of this potential, but the production estimated for 2000 is considerably in excess of the presently known potential.

For the satellites the hydroelectric potential is estimated at 80 billion kilowatt-hours. Even by the year 2000 the projected production amounts to only half of this value.

Available data are inadequate for making long range predictions for future prices. It has been estimated that the cost of an average ton of standard fuel will go down from about 80 rubles in 1958 to 50 rubles in 1965. About two-thirds of this reduction is the result of increased use of petroleum and natural gas.

The U.S.S.R. believes that they have ample reserves of petroleum. They are becoming an exporter of petroleum and this will continue for a good many years. Present exports are at the rate of 300,000 barrels per day and they are now supplying 15 percent of Italy's oil needs, 13 percent of Sweden's and 7 percent of West Europe's.[51] Exports have trebled in four years.[51]

CONSUMPTION AND SUPPLY OF ENERGY IN COMMUNIST CHINA

The data available for Communist China[52] are much less satisfactory than the scanty data for the U.S.S.R. No attempt will be made to present the energy picture for China in any detail, but only to show overall highlights.

The estimated production for coal and petroleum for 1959 and 1975 are as follows:

Year	Coal (millions of standard short tons)	Petroleum (millions of barrels)
1959	355	28
1975	920	350

Better than a 10-fold increase in petroleum production is expected in 15 years. Coal production will also increase sharply if planned goals are met.

Coal reserves are estimated at 1,000 billion tons and these appear ample to meet the requirements. Little data are available for recoverability or mining problems that may be encountered. No data are available on present petroleum reserves, but it is believed they are small. Whether adequate reserves can be developed to meet the estimated production for 1975 remains to be seen.

No data are available on either the production or reserves of natural gas.

Little is known about hydroelectric power in Communist China, but it has been indicated that the annual economic potential for 1967 is 1,000 billion kilowatt-hours and it is presumed that this is reasonable.

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[51] Business Week, May 7, 1960.
[52] From review staff memorandum.

LETTER REQUEST TO DEPARTMENT OF THE INTERIOR FROM SENATOR CLINTON P. ANDERSON, CHAIRMAN, JOINT COMMITTEE ON ATOMIC ENERGY

* * * * * * *

The scope and character of this review is comparable to the work in 1955 and 1956 of the committee's Panel on the Impact of the Peaceful Uses of Atomic Energy, of which Mr. McKinney was Chairman. You may recall that the Department of the Interior assisted the Panel by preparing a new and comprehensive estimate of energy resources and energy demand forecasts. These were published in volume II of the Panel's report, dated January 1956.

* * * We feel that this data on energy resources and demand forecasts should be updated in the course of the review now being conducted. * * *

I wish to request the cooperation of your Department, therefore, in the preparation of basic data for the review. * * *

* * * * * * *

TRANSMITTAL LETTER FROM DEPARTMENT OF THE INTERIOR

I am pleased to send with this letter two copies of our final report to the Joint Committee on Atomic Energy, on "Resources of coal, petroleum, natural gas, oil shale, and tar sands in the United States and allied and neutral countries." * * *

We trust that our report properly and adequately covers the information you desired.

* * * * * * *

RESOURCES OF COAL, PETROLEUM, NATURAL GAS, OIL SHALE, AND TAR SANDS IN THE UNITED STATES AND ALLIED AND NEUTRAL COUNTRIES

Prepared for the Joint Committee on
Atomic Energy
United States Congress

(Review of International Atomic Policies
and Programs of the United States)

United States Department of the Interior
March 1960

Purpose and Scope

The Department of the Interior has been asked to advise the Joint Committee on Atomic Energy, United States Congress, on the availability of coal, petroleum, natural gas, oil shale, and tar sands in the United States and allied and neutral countries. Forecasts of the future supply of these energy resources were to include consideration of changing economic conditions and a progressively improving technology. In time, the conditions to be considered were 1) those now existing--1960, 2) those 15 years hence--1975, and 3) those 40 years hence--2000.

Identification of Geographic Areas

For this study the United States and allied and neutral countries have been divided by the Department of the Interior into the nine geographic areas shown in Figure 1. The countries included in each area are listed in Table 1.

COAL

Problems of Appraising Coal Resources

Estimates of coal resources in different countries and even in different parts of the same country are rarely comparable because of wide variations in the definitions, procedures, and philosophies employed by different estimators and because of equally wide variations in the amount of data available.

The most important factor affecting the size of a coal resource estimate is the selection of the two major cut-off points--one at the minimum thickness of coal included in the estimate, and the other at the maximum depth of cover allowed above the coal. A conservative estimate may include only coal in thick beds and under slight overburden. A more generous estimate, on the other hand, may also include thinner, more impure, and more deeply buried beds. The maximum variation in cut-off points might produce a 5-fold difference in the size of estimates.

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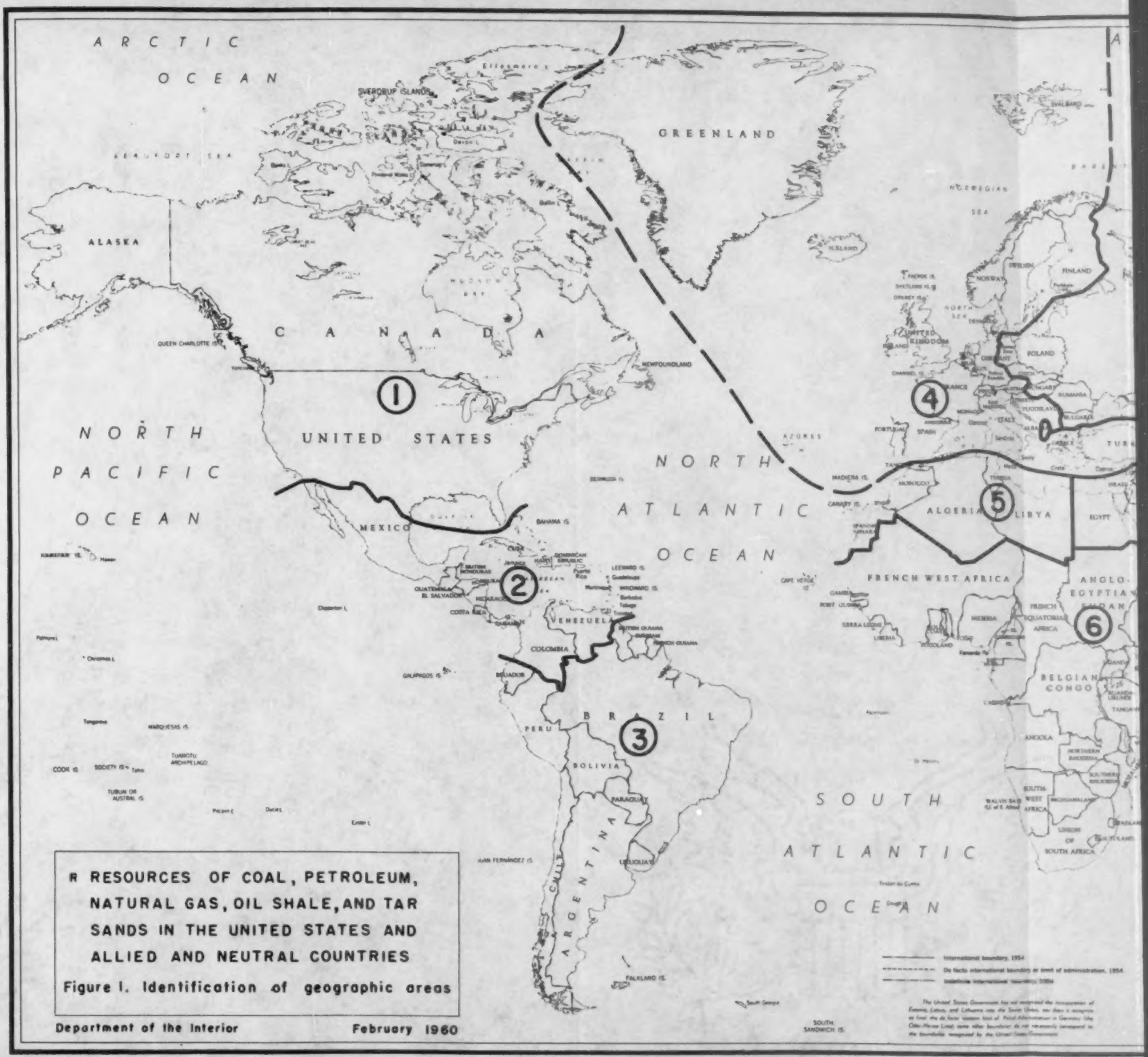

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ARCTIC
REENLAND
FRANZ JOSEF LAND
KARA
BARENTS SEA
NOVAYA ZEMLYA
NORWEGIAN SEA
SVALBARD
ICELAND
SWEDEN
FINLAND
NORWAY
FAEROE IS.
SHETLAND IS.
ORKNEY IS.
NORTH SEA
DENMARK
UNION OF SOVIET
UNITED KINGDOM
IRELAND
GERMANY
POLAND
CHANNEL IS.
FRANCE
AUSTRIA
HUNGARY
RUMANIA
SAAR
MONACO
ANDORRA
ITALY
YUGOSLAVIA
BULGARIA
PORTUGAL
SPAIN
Corsica
Sardinia
AZORES
GREECE
TURKEY
Malta
Sicily
Crete
Cyprus
SYRIA
IRAQ
IRAN
AFGHANISTAN
MADEIRA IS.
CANARY IS.
MOROCCO
TUNISIA
ISRAEL
JORDAN
ALGERIA
LIBYA
EGYPT
KUWAIT
SAUDI ARABIA
BAHREIN IS.
QATAR
TRUCIAL OMAN
MUSCAT AND OMAN
PAKISTAN
INDIA
ARABIAN SEA
LACCADIVE IS
MALDIVE IS.
CEYLON
SPANISH SAHARA
FRENCH WEST AFRICA
CAPE VERDE IS.
GAMBIA
PORT. GUINEA
SIERRA LEONE
LIBERIA
GHANA
NIGERIA
TOGOLAND
FRENCH EQUATORIAL AFRICA
ANGLO-EGYPTIAN SUDAN
ETHIOPIA
ERITREA
ADEN PROT.
YEMEN
BRITISH SOMALILAND
ITALIAN SOMALILAND
BELGIAN CONGO
KENYA
UGANDA
RUANDA-URUNDI
TANGANYIKA
ZANZIBAR
SEYCHELLES
CHAGOS ARCHIPELAGO
ANGOLA
NYASALAND
NORTHERN RHODESIA
SOUTHERN RHODESIA
MOZAMBIQUE
MADAGASCAR
SOUTH WEST AFRICA
WALVIS BAY (U. of S. Africa)
BECHUANALAND
SWAZILAND
BASUTOLAND
UNION OF SOUTH AFRICA
SOUTH ATLANTIC OCEAN
INDIAN OCEAN
PRINCE EDWARD IS.
CROZET IS.
KERGUELEN IS.
South Georgia
SOUTH SANDWICH IS.
International boundary, 1954
De facto international boundary or limit of administration, 1954
Indefinite international boundary, 1954
The United States Government has not recognized the incorporation of Estonia, Latvia, and Lithuania into the Soviet Union, nor does it recognize as final the de facto western line of Polish Administration in Germany. The Oder-Neisse Line; some other boundaries do not necessarily correspond to the boundaries recognized by the United States Government.

C O C E A N
SEVERNAYA ZEMLYA
KARA SEA
LAPTEV SEA
NEW SIBERIAN IS.
EAST SIBERIAN SEA
WRANGEL I.
VIET SOCIALIST REPUBLICS
BERING SEA
SEA OF OKHOTSK
ALEUTIAN ISLANDS
MONGOLIA
CHINA
SEA OF JAPAN
NORTH PACIFIC OCEAN
EAST CHINA SEA
RYUKYU ISLANDS
BONIN IS.
VOLCANO IS.
HAWAIIAN IS.
INDIA
BURMA
TAIWAN
8
8
BAY OF BENGAL
THAILAND
VIETNAM
SOUTH CHINA SEA
PHILIPPINES
CAROLINE IS.
PALAU IS.
MARSHALL IS.
GILBERT IS.
MALAYA
BRUNEI
SINGAPORE
SARAWAK
INDONESIA
CHAGOS ARCHIPELAGO
COCOS IS.
ARAFURA SEA
PAPUA
SOLOMON ISLANDS
ELLICE IS.
CORAL SEA
NEW HEBRIDES
FIJI IS.
SAMOA IS.
9
AUSTRALIA
TASMAN SEA
NEW ZEALAND
CHATHAM IS.
BOUNTY IS.
ANTIPODES IS.
AUCKLAND IS.
MACQUARIE IS.
D I A N
O C E A N

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Table 1.--List of geographic areas for review of resources of coal, petroleum, natural gas, oil shale, and tar sands

1. North America:
   - Canada
   - United States

2. Caribbean America:
   - Barbados
   - British Honduras
   - Columbia
   - Costa Rica
   - Cuba
   - Dominican Republic
   - Guatemala
   - Haiti
   - Honduras
   - Mexico
   - Nicaragua
   - Panama
   - Puerto Rico
   - Trinidad and Tobago
   - Venezuela
   - All other islands

3. Other South America:
   - Argentina
   - Bolivia
   - Brazil
   - British Guiana
   - Chile
   - Ecuador
   - French Guiana
   - Paraguay
   - Peru
   - Surinam
   - Uruguay

4. Western Europe and Turkey:
   - Austria
   - Belgium and Luxembourg
   - Denmark
   - Finland
   - France
   - Western Germany
   - Greece
   - Greenland
   - Iceland
   - Ireland
   - Italy
   - Netherlands
   - Norway
   - Portugal
   - Saar
   - Spain
   - Svalbard
   - Sweden
   - Switzerland
   - Turkey
   - United Kingdom
   - Yugoslavia

5. North Africa:
   - Algeria
   - Libya
   - Morocco
   - Spanish Morocco
   - Spanish Sahara (Rio de Oro)

Table 1.--List of geographic areas (continued)

6. Other Africa:
   - Angola
   - Bechuanaland
   - Belgian Congo and Ruanda-Urundi
   - British Somaliland
   - Ethiopia (incl. Eritrea)
   - French Cameroons (Kamerun)
   - French Equatorial Africa equivalents
   - French West Africa equivalents
   - Gambia
   - Ghana
   - Kenya
   - Liberia
   - Madagascar
   - Mauritius
   - Mozambique
   - Nigeria and British Cameroons
   - Portuguese Guinea
   - Rhodesia and Nyasaland, Fed. of
   - Rio Muni
   - Sierra Leone
   - Somalia
   - South West Africa
   - Sudan
   - Tanganyika
   - Tunisia
   - Uganda
   - Union of South Africa (incl. Basutoland and Swaziland)

7. Middle East:
   - Bahrein
   - Egypt
   - Iran
   - Iraq
   - Israel
   - Jordan
   - Kuwait
   - Lebanon
   - Neutral Zones
   - Qatar
   - Saudi Arabia (incl. Yemen, Aden Protectorate, Muscat and Oman, and Trucial Oman)

8. Far East:
   - Afghanistan
   - British North Borneo
   - Brunei
   - Burma
   - Cambodia and Laos
   - Ceylon
   - India
   - Indonesia (incl. Timor)
   - Japan
   - Malaya and Singapore
   - North-East New Guinea
   - Pakistan
   - Papua
   - Philippines
   - Sarawak
   - South Korea
   - Taiwan
   - Thailand

9. Australia and New Zealand:
   - Australia
   - New Caledonia
   - New Zealand
   - Other oceanic islands

(This list is ancillary to the map (Figure 1), and is not necessarily complete. It follows as closely as possible the format of UN Statistical Paper Series J No. 2.)

The second most important factor affecting the size of a coal resource estimate is the area and tonnage of coal considered to be established by each thickness measurement or group of measurements. Some estimates, for example, include only coal proved up by closely spaced drilling or trenching; others assume correlation between more widely spaced points of information, and include larger areas of coal on the basis of smaller amounts of information. The maximum variation in both this factor and the first factor might together produce a 10-fold difference in the size of estimates.

The third most important factor affecting the size of a coal resource estimate is the assumption made as to the continuity of coal beds. In some older estimates the coal beds are considered to be tabular bodies that extend uninterruptedly to the farthest limits of the area being studied. In others the coal beds are considered to be lens-shaped bodies of limited areal extent. In the Geological Survey's recent estimates of United States resources an individual bed that is known only in its outcrop is considered to extend back of the outcrop in a semicircular area having a radius equal to half the length of the known outcrop. In other countries broader continuity is assumed. The maximum variation in assumptions as to the continuity of beds might produce a 2- or 3-fold variation in estimates.

Resource estimates are frequently large when based on a small amount of data, and small when based on relatively larger amounts of data. This inverse relationship is readily explained. In areas where very little information is available on the number, thickness, and continuity of coal beds, the estimators tend to extrapolate the known information over the entire area being studied, and thus obtain a relatively large estimate. On the other hand, where there are larger amounts of information the estimators tend to restrict the estimates to the areas of such information and thus obtain relatively smaller estimates.

As to relative worth, the larger estimate based on less information may correspond more closely to the actual total amount of coal that may in the future be proved to be present. But the smaller figure based on more data generally reflects greater detail and accuracy of the type needed for mine development, although it applies only to a part of the total geologically-inferrable coal resources.

Older resource estimates are generally based on relatively smaller amounts of data and are generally based on assumed broad continuity of coal beds. For these reasons older resource estimates tend to be relatively larger than more recent estimates.

The inverse relationship between the size of a resource estimate and the amount of data on which it was based does not always hold. In some countries and areas where there is a very large amount of information and where coal beds can be correlated and projected across structural basins, the estimates tend to be relatively large. In other countries and areas where information is meager the estimates may be made more conservatively, without significant projection of information available, and thus be relatively small.

Other factors affect the size of coal resource estimates to varying degrees. A few countries report original resources in the ground before mining began; others report remaining resources in the ground as of the date of the estimate. Both kinds of estimates are used in the accompanying table, but the discrepancies thus introduced are of very little significance. More rarely a country will report recoverable resources--a figure that is typically about half of remaining resources. As far as is known, all of the estimates in the accompanying table are either for original or remaining resources in the ground--none is for recoverable resources.

Canada provides a very good example of the effect of changes in methods in calculating coal resources. In 1913, the remaining coal resources of Canada were estimated to total 1,216,770 million metric tons (Twelfth International Geological Congress, 1913). In 1946, the remaining coal resources in Canada were re-estimated to total only 89,644 million metric tons (MacKay, 1947). This new figure is less than 8 percent of the older figure, although the amount of coal mined from 1913 to 1946 would reduce the old figure by only about one twenty-fifth of one percent. The 1913 estimates assumed broad continuity of coal beds based on few actual observations, and made statistical allowance for all possible beds to a minimum thickness of 1 foot and to a maximum depth of 4,000 feet below the surface. The 1946 estimate included only known, developed, or explored beds, which for reasons of thickness, quality, and extraction costs were considered to be economically minable in 1946. Similarly, the present estimate of United States resources is only about half of the 1913 estimate, largely because of more restrictive assumptions as to the continuity of coal beds, and to a lesser extent because of the elimination of areas for which data are not available.

Technology of Production and Transportation

In considering the availability of energy from the coal resources of the United States and allied and neutral countries, it is assumed that a free interchange of technical information will eventually result in an equalization of mining practice in equivalent coal deposits. However, variations in the

deposits will inevitably lead to differences in integrated mining systems, designed not only to suit the local geological conditions but also economic conditions based on labor rates, capital costs, taxes, etc.

These differences have contributed to a wide variation in productivity from mine to mine, locality to locality, and country to country. For example, in 1958 the average productivity per manshift was 11.33 net tons in the United States and 1.41 in Great Britain. Nevertheless, the purpose of this study can perhaps best be served by assuming that productivity and other economic factors will be subject to the same changes proportionally country by country as in the United States. Accordingly, the discussion that follows is based on current and projected practice in the United States.

About 70 per cent of the output of coal and lignite in the United States is mined underground. The major tasks underground are cutting, drilling shotholes, loading, and hauling. For many years most of the underground production was obtained by the use of conventional undercutting machines and power drills for shotholes. However, in recent years the percentage of coal mined by continuous mining machines has been increasing, and consequently the percentage mined with the use of undercutting machines and power drills has been correspondingly decreasing. In 1958, about one-seventh of total output was produced by continuous mining machines. Loading machines have not been seriously affected by the use of continuous mining machines; in 1958, 35 per cent of the coal produced in underground mines in the United States was loaded mechanically. Underground haulage is principally by trolley locomotive, but the use of conveyors is steadily increasing.

About 28 per cent of the output of bituminous coal and lignite in the United States is produced by strip mining. The rapid growth of strip mining was made possible by the development of larger and improved stripping and drilling equipment and trucks. The most notable recent change has been replacement of virtually all steam shovels by diesel-powered and large electric shovels and draglines. The largest shovel in the world was built for coal strip mining. This shovel has a bucket capacity of 70 cubic yards, and can handle 120 feet of overburden. The average overburden at all strip mines in the United States was 42 feet and the average thickness of coal seam mined was 4.9 feet in 1955, the latest year for which figures are available. As much as 120 feet of overburden is stripped at some places. The average thickness of coal seam mined by strip mining has been decreasing. This thickness was 5.2 feet in 1946, 5.0 in 1950, and 4.9 in 1955. The ratio of overburden to coal is usually expressed as cubic yards of overburden per net ton of coal. This ratio was 9.1 in 1946, 10.7 in 1950, and

12.3 in 1955. It would be reasonable to assume that currently the ratio is 14 cubic yards of overburden per net ton of coal. An increase in average capacity of trucks used in strip mines has reduced the number required. The average hauling distance from the strip mines to tipples or ramps has remained approximately 4 miles.

The rapidly expanded production of coal by stripping during World War II in the mountainous areas of the northern Appalachian region of the United States exposed many miles of coal seams extending back under overburden too thick for further economical strip mining. After some experimentation, large, efficient augers as much as 60 inches in diameter were developed to recover the coal from these exposed seams. Nearly 2 per cent of the coal mined in the United States is now produced by auger mining. Augers were used to mine coal in eight states in 1958, and sales of augers reported by manufacturers indicate continued growth of auger mining. A few coal-recovery augers have been sold for underground use.

Progress in mechanization is expected to continue both in improved methods and in extent.

In the United States in 1958, Class I mines, i.e. mines producing 500,000 net tons or more annually, were only 2.4 per cent of the total number of mines producing bituminous coal and lignite but accounted for 45.2 per cent of the output. By 1975 the number of Class I mines will increase, and their total output is expected to account for about 90 per cent of the bituminous coal and lignite production. The technology of underground mining will be transformed mainly in the direction of integrated operation of continuous mining machinery and haulage equipment in the new mines opened during the next 15 years.

In strip mining operations, new developments in shovels and wheel excavators will make it possible to extend the amount of strippable reserves, and perhaps for a while increase the percentage of coal produced by strip and auger mining. By 1975, however, as the total demand for coal will increase, the remaining strippable reserves are likely to be inadequate to maintain the higher percentages of coal produced by strip and auger mining, and the present tonnage relations of strip, auger, and underground mining again will be restored.

Whether or not approximately the present relation between mining methods will prevail, the expected increase in output from Class I mines will be based on full mechanization of these mines by 1975.

It would be rash to assume that new and undreamed of methods of mining will not be developed in the final quarter of this century. One new method already envisioned and in progress of development in the United States and abroad is that of hydraulic underground mining. In this method a jet of water leaving a nozzle at pressures that may exceed 4,000 pounds per square inch is used to cut the coal from the face. It is anticipated that by this method coal could be mined at even greater rates than by continuous mining machines. In conjunction with hydraulic mining it would be natural to anticipate full development of hydraulic transportation of the coal from the face to the surface.

After cleaning and sizing, further transport of much of the coal on the surface will be by hydraulic or pneumatic transportation in long-distance pipelines to the points of consumption. The problem of drying will be transferred from the preparation plants to the receiving stations.

Strip and auger mining will diminish relatively and possibly absolutely as strippable reserves are depleted, even if the equipment for these operations should attain capability of stripping much greater depths of overburden economically in relation to the then expected methods of underground mining.

Labor Productivity

In the United States the 1958 labor productivity in net tons per man-day averaged 9.38 in underground, 21.54 in strip, and 28.15 in auger mining. The overall average was 11.33 net tons per man-day.

The overall average productivity since World War II has been just about doubled. Most of it may be accounted for by the very high rates of productivity in strip and auger mining, but much may be attributed to mechanization underground. A straight line projection over the next 15 years for the United States would yield an overall average productivity per man-day of 20 net tons. Indications, however, are that gains in productivity in strip and auger mining will flatten off. Nevertheless, it is not unreasonable to expect a productivity rate per man-day of 15 to 18 net tons by 1975.

Additional improvements can be expected by 2000. In the normal course of technological development progress may be accepted as a certainty. The extent of this progress will depend on many unforeseen factors. In the case of hydraulic mining and transport, questions of water supply--its delivery from the source to the mine, and, if necessary, its return from the pipeline terminals to

the coal preparation plants--may have a retarding effect on the extent of their industrial application.

Considering that hydraulic methods will have a significant part in the total coal mining industry, and combining them with improvements in presently applied methods and with still unimagined equipment, an average productivity of 25-35 net tons per man-day is more than likely by the year 2000. This prognostication may well prove to be conservative, in view of the present capability of continuous mining machines operating in conjunction with loaders and shuttle cars to yield 40 to 75 net tons per man at the face, depending on the thickness of the seam. Furthermore, automation will tend to reduce the number of men engaged in handling the coal produced by the men at the face.

Costs

Satisfactory details in costs of mining are difficult to obtain, but they bear a reasonable relation to the sale price of the coal or the value assigned to it by the producer, as in captive operations.

In 1958 the average price in the U. S. of coal, f.o.b. mines, sold in the open market was $4.58 per ton, the average value of coal not sold in the open market was $6.41 per ton, and the overall average was $4.86 per ton. The relative prices per ton, f.o.b. mines, were $5.33 for underground mines, $3.80 for strip mines, and $3.60 for auger mines.

Seventy-five per cent of the coal is moved by rail, and railroad transportation has averaged $3.58 per net ton in 1958. Comparable figures are not available for barge and truck transportation between the same points served by the railroads, but in one instance, where the distance by river is 266 miles, the barge rate is 55 cents per net ton in contrast to the rail rate of $1.56 per net ton.

Reserves are such that thickness of seams and depth of underground mining operations should not change significantly within the next 15 years. (See section on "Recoverable coal"). Accordingly, mining costs, on the basis of a constant dollar, will tend to decrease because of expected acceleration of increasing productivity, even though the gains will tend to be absorbed by capital cost of mechanization and by increased wages. The average value of coal f.o.b. mines may show little change through 1975, at outputs and plant utilization comparable to those cited for 1958. The trend toward the concentration of operation in large mines will accelerate the trend toward shipments of coal in larger trainloads and larger cars. Freight costs may therefore decrease.

Improvements in technology between 1975 and 2000 will continue to tend to decrease the cost of mining the coal, counterbalancing trends of rising wage rates and prices of other inputs under constant dollars. There is no doubt that in the United States enough coal deposits under cover of 1000 feet or less are available under mining conditions similar to those now in existence to supply the projected energy needs until 2000. Such methods as hydraulic mining are expected to result in reduced capital investment in continuous mining machinery, and underground hydraulic transport will reduce the investment in haulage equipment and the sizes--and hence the costs--of haulageways and shafts. Hydraulic or pneumatic transportation of coal in long-distance pipelines will have a further effect in lowering the delivered cost of the coal to the consumer.

Resources of Coal

Table 2 gives the coal resources of the geographic areas included in this study according to two viewpoints. The column headed "Total resources" is made up of the larger figures calculated and reported by the various countries. For some countries this figure includes inferred resources and resources in thin and remote beds; for other countries (e.g., Canada) the figure includes only known minable or proved resources. This discrepancy cannot be avoided with the information at hand. The column headed "Resources of probable economic interest in the period from 1960 to 2000" includes only proved reserves as reported by various countries where this information is available. Where this information is not available (e.g. most of Caribbean and South America) a figure equivalent to approximately 25 per cent of total resources has been used. This factor corresponds, in the United States, to the amount of measured and indicated reserves in beds 28 inches or more thick (5 feet or more in the case of lignite and subbituminous coals) and less than 2,000 feet below the surface. Use of this percentage factor permits a comparison between regions on the more conservative basis. Both columns have value in appraising the coal resource potential of the several regions.

Recoverable Coal

In the U.S.A., approximately 60 per cent of the resources of probable economic interest in the period from 1960 to 2000 is in thick beds (over 42 inches thick for anthracite and bituminous coal; over 10 feet thick for subbituminous coal and lignite), and is therefore available for mining at present prices with present technology. Assuming a recovery of 50 per cent the following quantities (Table 3) will be available for use during the period from 1960 to 2000:

Table 2. Estimated remaining coal resources of the United States and allied and neutral countries[1]/
(In millions of metric tons)

Geographic area	Total resources			Resources of probable economic interest in period from 1960 to 2000[2]/		
	Anthracite, bituminous and subbituminous coal	Lignite and brown coal	Total	Anthracite, bituminous and subbituminous coal	Lignite and brown coal	Total
North America	1,162,382	430,420	1,592,802	317,227	113,709	430,936
Caribbean America	19,375	4	19,379	4,129	4	4,133
Other South America	3,555	250	3,805	890	60	950
Western Europe and Turkey	420,495	79,526	500,021	205,674	70,385	276,059
North Africa	20	--	20	5	--	5
Other Africa	69,630	200	69,830	37,942	13	37,955
Middle East	--	--	--	--	--	--
Far East	73,022	3,877	76,899	9,069	1,330	10,399
Australia and New Zealand	16,899	41,785	58,684	5,545	7,122	12,667
Total	1,765,378	556,062	2,321,440	580,481	192,623	773,104

1/ Data from Statistical Yearbooks Nos. 4, 5, 6, 7, and 8 of the World Power Conference, London, (1948, 1950, 1952, 1954, and 1956), with revisions from several United Nations publications, the Mexico Departmento de Estudios Tecnicos y Economicos, and the Philippine Bureau of Mines.

2/ Most of the figures in these columns represent proved reserves, but for some countries where estimates of proved reserves are lacking, assumed figures approximately equivalent to twenty-five percent of total reserves have been used.

Table 3.--Coal estimated to be available for use between 1960 to 2000, assuming a recovery of 50 percent

Geographic area	Million metric tons	Trillion B.t.u.
North America	215,000	6,200,000
Caribbean America	2,000	58,000
Other South America	500	14,000
Western Europe and Turkey	138,000	3,980,000
North Africa	1/	2/
Other Africa	19,000	548,000
Middle East	-	-
Far East	5,200	150,000
Australia and New Zealand	6,300	182,000
Total	386,000	11,132,000

1/ Two and one-half million metric tons.
2/ Seventy-seven trillion B.t.u.

Actually the average recovery might well exceed the 50 percent figure; it already reaches 70 percent within the most modern mines. Thus, an average of about 10 billion tons a year is available between now and the year 2000.

Specific annual production at any given time will be controlled by the prevailing price and technology. For the United States, Table 4 shows the estimated tonnage of coal that could be produced, on the assumption that the demand for energy will be great enough to establish competitive prices at the alternative levels shown, and at the kind of technology that might reasonably exist in the years 1975 and 2000.

The relationships shown are calculated from the historical responses of production to price, modified for the future on the expectation that the cost-cutting results of mechanization will have increasing weight in relation to rising wage rates. The 1958 figures are based on 180 days of production; for 1975 and 2000 the mines are presumed to operate at 250 days a year.

The projections given represent not forecasts of production, but only a judgment of capabilities and responses. Actual prices and levels of production will be governed not only by the supply-response of coal, but also by availability and price of competing fuels for industrial uses. For example, if all fuel prices change proportionately, at a price of $4.86 per ton of coal in 1975 (in 1958 dollars) the demand for coal would amount to 700 million tons; at a price one-fourth higher the demand would decrease 360 million tons, whereas at a price less than $4.86 a ton the demand would be more than 700 million.

To illustrate the effect of improved technology, it is calculated that if technology remains at the present level while cost of labor and supplies go up, 1975 production would be only three-fourths of what it otherwise would be at the various price levels shown; or, stated differently, that about a 50-per cent higher price would be required to bring out equivalent production.

Table 4. U. S. Coal production at alternative price levels and stages of technology

Million Tons of Coal

Mine price in 1958 dollars	Technology		
	1958 Actual	1975 Expected	2000 Likely
$4.86 per net ton	410	565	590
1/4 lower	335	455	480
1/4 higher	485	665	690
1/2 higher	550	750	775

Physical Capacity to Produce Coal

Production of bituminous coal and lignite in the United States in 1958 totaled 370 million metric tons (410 million tons of 2,000 pounds) and production of anthracite coal totaled 17.2 million metric tons (19 million net tons). As indicated above, this was produced over an aggregate working period of almost exactly half a year, on a one-shift basis. Had the physical plant been fully utilized and operated 24 hours a day for three-fourths of a year--allowing some nonutilization for maintenance and repair--4-1/2 times as much coal could have been mined. Conditions elsewhere in the world are not necessarily similar, and data are not at hand for analysis, but the relation between actual production and present physical capability may be presumed to permit considerable expansion of coal output, provided labor is available.

The capacity of mines in the United States and its allied and neutral countries is thus several times the present rate of consumption in these countries. Should demand become so great as to require even greater capacity, each additional 100 million net tons of capacity would call for an investment of about one billion dollars, based on 1956 U. S. prices and U. S. mining practice.

Based on present productivity rates in the United States an increase in production of 100 million net tons a year would require somewhat more than 10 million man-days of work. Depending on the number of days worked a year, the necessary additional labor force would be some 30,000 to 40,000 men. Because of improving productivity, by 1975 the additional labor required should be only two-thirds as much, and by the year 2000 about half as much.

Although local shortages may develop, on an overall basis no ceiling is envisioned on the rate of production imposed by the amount of coal in the ground and its geological characteristics.

Supply of Metallurgical Coal

Metallurgical coal, i.e., coal for producing metallurgical coke, is mined essentially the same way as any other coal. Occasionally coal near an outcrop that has been exposed too long may be so oxidized as to have its coking properties impaired. This is a situation that is expected to arise only rarely where mining proceeds at a normal pace.

The standards for coal charged to coke ovens vary with the availability of coking coal. Various coals are mixed to provide suitable blends for charging into the coke ovens. Where shortages of suitable blending stock exist a variety of expedients have been employed successfully to over come them. Further developments in the art of coke manufacture will continue as the need arises. In Lorraine, for example, by tamping the charge of what would be considered a poor coking coal by American standards, its bulk density is so increased as to yield a suitable metallurgical coke. Where shortages of low-volatile blending stock exist, char produced from high-volatile coal is substituted. Many other examples may be cited to illustrate how shortages of coking coal are overcome to produce suitable coke for metallurgical purposes. Furthermore, progress in metallurgical technology has been such that coke may be entirely replaced, if necessary, by a variety of reducing agents which may be derived from coal normally considered unsuitable for coke production.

PETROLEUM AND NATURAL GAS

Problems of Appraising Petroleum and Gas Resources

Petroleum and natural gas occur far beneath the surface and cannot be measured until brought to the surface. Quantities remaining underground can only be estimated. Experience has shown that estimates of the quantities yet to be produced from areas already drilled (proved reserves), and estimates of the producible quantities in undrilled areas (undiscovered petroleum and natural gas), tend to be very conservative, particularly the latter estimates.

Accumulations of petroleum and natural gas are discovered by relatively widely spaced exploratory wells. Once discovered, their limits are determined by more closely spaced development wells. The limits of most fields are not fully determined by development drilling until many years or many decades have elapsed. But soon after discovery, estimates are made of the proved reserves of the part already drilled. These estimates generally involve estimation of the total oil content of the reservoir proved by drilling, and estimation of the percentage of that total that can be extracted profitably. These two factors yield an estimate of the "ultimate reserves" (total amount producible) of the drilled part of the field, from which the proved reserve estimate is derived by subtracting the cumulative past production.

As more and more is learned about the producing characteristics of the reservoir as the pool is produced, and as the known extent of the reservoir is increased by new development wells, the estimates of the "ultimate reserves" are generally increased markedly. Changes in the estimates that apply to previously drilled parts of the field are called "revisions"; those that result from new development drilling are called "extensions."

In the United States, beginning at the end of 1936, the American Petroleum Institute has published yearly summary estimates of the proved reserves of crude oil in all fields. Beginning at the end of 1945, estimates of proved reserves of natural gas, by the American Gas Association, were added to the report. A year later, separate estimates for reserves of natural gas liquids were begun. Beginning in 1957, estimates for petroleum and natural gas in Canada, prepared by the Canadian Petroleum Association, were added to the yearly summary.

These yearly proved-reserve estimates have been frequently misinterpreted as representing the total underground quantities producible if no new fields were subsequently found. Actually, the record of the past shows that there would be

substantial increases through revisions and extensions even if no new fields were discovered. The quantities added to reserves of pre-1937 discoveries have already considerably exceeded the proved-reserve estimate at the end of 1936. It is not unlikely that by the time the reservoirs discovered prior to 1937 have been produced to the economic limit, their post-1936 production will be at least 3 times the proved-reserve estimate at the end of 1936.

From time-to-time attempts have been made to predict the amount of undiscovered petroleum and natural gas in specified geographic areas. Most of these have been in the form of estimates of "ultimate reserves," i.e., what the cumulative production from both discovered and undiscovered pools would eventually total. For the United States, all such estimates made prior to 1950 have proved to be much too low.

In attempting to estimate the quantity of petroleum and natural gas in rocks not yet explored, the estimator must logically use the quantitative results of previous exploration as a "yardstick." But this "yardstick" is constantly changing in length. Thus, most estimators have considered cumulative production plus proved reserves to represent the total quantity found to the date of the estimate. But, as discussed above, unknown but considerable quantities will be added to the reserves of known fields by revisions and extensions over many decades. Moreover, not all the producible deposits that have been drilled through have yet been detected! For example, in 1957 and 1958, some 48 entirely new fields were found by reentering and retesting old "unsuccessful" wells, according to statistics of the Committee on Statistics of Exploratory Drilling of the American Association of Petroleum Geologists. Hence there is no accurate measure of the quantities already found.

The problem of quantitatively appraising potentially productive rocks as yet undrilled, or only sparsely drilled, is far more formidable. Geology has been very successful in determining what areas are potentially productive and in guiding exploration within those areas. But the kind of information needed for true quantitative appraisal can be provided only by substantial amounts of actual drilling. As long as the volume of unexplored potentially productive rock greatly exceeds the volume already explored, all estimates of undiscovered quantities are subject to major revision.

Considerably more exploratory drilling has been done in North America than in the other continents, but even in North America only a relatively small fraction of the potentially productive rock has been explored. Exploratory drilling is

continuing in even the most densely drilled geologic provinces, and new discoveries are made yearly in such areas. The United States and Canada contain more than 3 million square miles underlain by potentially productive sedimentary rocks ranging from 1,000 to more than 40,000 feet in thickness. To explore this mass to a depth of 30,000 feet or to the base of the sedimentary rocks, whichever is reached first, would require drilling to an average depth of at least 7,000 feet. Because many fields are less than two square miles in areal extent an average of at least one exploratory well per two square miles would be required for near-exhaustive exploration of the entire area. This would require something on the order of 11 billion feet of exploratory drilling. For comparison, the total footage of exploratory drilling in the United States and Canada so far is approximately 1 billion feet. In other words, roughly 10 times as much potentially favorable rock by volume remains to be explored as has been explored so far.

It is considered very unlikely at present that the average incidence of petroleum and natural gas in the unexplored rocks is as great as in the rocks already explored--the best prospects, as indicated by current information, are generally drilled first, but new major deposits are generally found with continued exploration. Sizeable portions of the unexplored rock volume may have an incidence of petroleum and natural gas that is much less than in the rocks already explored--in such cases many of the deposits would never be found because intense exploration would not be economically justified. But none of the potentially productive rocks can be classed with assurance as largely barren of petroleum and natural gas on the basis of present information. To what extent the potentially productive rocks are explored will depend not only upon the natural incidence of petroleum and natural gas in those rocks, but also upon the extent to which technologic progress offsets possible increased difficulty in finding deposits, and upon how petroleum and natural gas fare in future competition with other sources of energy.

Technology of Production and Transportation

The modern petroleum and natural gas industry was brought into being by a realization of the value of both crude oil and natural gas. The utility of natural gas was known and commercially exploited in the United States long before Colonel Drake "drilled the first oil well" in 1859. Drake's well was drilled directly as a result of Professor Silliman's scientific examination of a crude oil sample and his detailed report of the many useful and needed products that could be obtained from petroleum in quantity.

Technology advanced oil finding from the art of looking for oil along creek banks where oil seeps occurred to the complicated scientific exploration approach used today. The wasteful uncontrolled production of oil as fast as the well would flow it has been replaced by engineered controls extending recoveries and by methods to increase recovery, such as pressure maintenance and waterflooding. Transportation of oil in barrels by horse-drawn wagons has been replaced by pipelines extending thousands of miles and by sea-going tankers with capacities of over half a million barrels, and carrying oil on trips extending half-way around the world.

Direct fracturing or parting of oil formations by hydraulic pressures has been used to increase production in many old and new wells and to allow production from oil sands that would not otherwise be productive. Reserves have been increased greatly. Over 80 percent of all new wells completed today have had some kind of fracturing treatment. Combusion of oil in place in the ground has been proved feasible and is a possible method for greatly increasing total recovery from individual fields and for production from other reservoirs that cannot produce by conventional methods.

In drilling there has been a steady improvement in materials, rigs, control, power, bits, drilling mud and its treatment, and pipe. The depth record again toppled with the completion of a 25,000 foot-deep dry hole in West Texas in 1958. Quadruple well completions entered the picture in the same year. This allows production from four different horizons or reservoirs through small-diameter pipes all within one single hole or well.

Use of air or gas instead of drilling liquids is a proven technique advantageous in some drilling. Percussion hammer drills, and the turbine drills, used widely in Russia, have been tried in this country and have decided advantages over the rotary system in some types of formations. Rigs for drilling slim holes, speeding-up drilling and cutting down pipe costs, constitute another advance used widely.

Average contract price in current dollars has held almost constant over the last 13 years, although the costs of labor, steel and other inputs have approximately doubled and average depths are 20 percent greater. Total completion costs in constant dollars at constant average depth have remained constant despite a steadily rising portion of costs required for post-drilling completion.

In another development, wells are flowed automatically on a set schedule and rate, production is automatically measured, and oil is transferred automatically from leases to pipelines. Labor costs for pumpers or gaugers are eliminated or reduced.

Waterflooding continues to expand, along with other methods for increasing oil recoveries. Today over 500 pressure-maintenance projects are in operation.

The trend in U. S. field development practice has been to a wider spacing of wells. Production has been assisted through the use of better well completion methods to improve the producing characteristics of wells. Unitization of oil fields has increased in many of those regions where there is multiple ownership of land. This permits, through agreements of the operators and royalty interests, the operation of a reservoir as a unit.

The effect of technological progress in petroleum production can be measured in terms of increase in capacity per producing well and in terms of increase of total recovery of oil per well. For the 15-year period 1943-1958 the average capacity of each producing well in the United States has increased almost 50 percent, from 11.6 barrels to 17 barrels. A projection of this trend indicates a further increase in capacity to 21 barrels by 1975. Also from 1943 to 1958, the total expected production from each well has increased 50 percent. As a result, one-tenth fewer wells will have to be drilled to sustain the present productive capacity over the next 15 years. On the other hand, average well depth and the percentage of dry holes drilled have been increasing, so total footage drilled would increase despite a comparative decline in the number of completed oil wells.

In sea-going tanker transportation the most obvious development has been an increase in the size and speed of oil tankers. The largest ship afloat of any type in 1959 was the oil tanker Universe Leader, 85,515 deadweight tons, transporting 600,000 barrels of oil at a speed of 15 knots. Soon to be completed is a giant 106,500 ton tanker that will carry 825,000 barrels and travel at 17 knots. Nuclear-powered oil tankers (or submarines) may be the next feature. On inland rivers and waterways the largest modern barge combinations carry from 175,000 to 200,000 barrels of oil each trip with great economy. Tank car sizes have recently doubled from 10,000 to 20,000 gallons and corresponding growth has taken place in tank truck capacities which enables considerable reduction in costs.

The limit has not been reached in maximum pipeline diameters for the long distance movement of petroleum, petroleum

products, and natural gas, but far more important is the steady growth in average pipeline diameter. These and other known techniques, plus others that are sure to come, clearly indicate that large gains can be expected in the next 15 years.

Ocean transportation of liquid methane has been demonstrated. Utilization of the now-wasted natural gas production in the Middle East and elsewhere thus approaches reality. Underwater natural-gas transmission from Africa to Europe may become feasible.

A look backward in time of 40 years brings a realization that one cannot forecast specific and definite developments in methods, tools, instruments, or other items corresponding to such things around us and in use today. One thing is clear: measureable gains in the next 40 years should be at least equal to the percentage gain seen in the past 40 years.

Some experts believe that by the year 2000 science will be able to locate oil and gas in the ground before a well is drilled. This latter accomplishment would allow the proving of petroleum and natural gas reserves on a scale far ahead of what we can do now, with the elimination of many of the 8 dry holes out of every 9 wells now drilled to find an oil reservoir, of either minor or major proportions.

Resources of Petroleum and Natural Gas

United States and Canada

Estimates of proved reserves, and most estimates of undiscovered petroleum and natural gas, refer to the quantities producible by conventional techniques and under economic conditions prevailing at the time of the estimate. Only a fraction of the petroleum in subsurface reservoirs is so producible. For example, the Secondary Recovery Committee of the Interstate Oil Compact Commission has estimated that the original crude oil in place in drilled portions of known reservoirs in the United States at the beginning of 1958 was approximately 310 billion barrels. About 58 billion barrels had been produced to that time, leaving a remainder of 252 billion barrels. Only a little more than 30 billion barrels of this underground quantity was considered proved reserves according to the American Petroleum Institute estimate at that time. The remaining 220 billion barrels, approximately, includes the crude oil that will be added by "revisions" to proved-reserve estimates together with oil that will never be recoverable. Just how much will become producible will depend upon technologic progress and economic conditions in the future.

Proved-reserve estimates of natural gas liquids reflect only a fraction of such liquids in drilled portions of known reservoirs, for those estimates are based in part on the number and technology of existing processing plants. Thus, recent proved-reserve estimates show a ratio of only about 25 barrels of natural gas liquids per million cubic feet of natural gas, whereas the natural occurrence is more on the order of 60 barrels per million cubic feet. The proportion of natural gas production that is treated to recover the liquids can be greatly increased, and considerable improvement in the average recovery of liquids from the gas so treated is technologically possible. Here again, just what proportion of these potential additional resources will be utilized in the future will depend upon technologic progress and economic conditions.

A much greater percentage of the natural gas in drilled portions of known reservoirs is recoverable by conventional production techniques than is the case with crude oil. Hence proved-reserve estimates of natural gas include a greater proportion of the amount in the ground. However, the proved-reserve computations generally assume a terminal pressure beyond which continued operation would be unprofitable in the present economy. Considerable quantities, generally from 5 to 25 percent of the original quantities, would remain underground with present producing practices.

Because the extent of recovery of these oil and gas underground resources is subject to much change resulting from technologic progress and changing economic conditions, there is a growing tendency to give greater emphasis to the total underground quantities in long-range considerations.

The estimated quantities in Table 5 are generalized and are intended to represent only orders of magnitude. Items 3, 4, and 5 in the table include large quantities that are not considered economically recoverable at present, and smaller quantities that are not technologically recoverable at present regardless of cost.

Table 5.--Resources of petroleum and natural gas in the ground in the United States and Canada (Jan. 1, 1960)

	Total liquid hydrocarbons (billions of barrels)	Natural gas (trillions of cubic feet)	Explanatory note (see below)
1. Past extraction	80	250	A
2. Proved recoverable reserves	41	280	B
3. In the ground in drilled portions of known reservoirs	300	350	C
4. In the ground in possible extensions of known reservoirs	75	200	D
5. In the ground in undiscovered deposits	1500 - 2500	3000 - 5000	E

Explanatory note A - The estimate for natural gas includes a very rough estimate of the large but unrecorded quantity of natural gas wasted in the early history of oil developments. The estimate for liquid hydrocarbons includes rough allowance for the quantities of natural gas liquids in this wasted gas, and also the quantities that were not recovered from recorded production of natural gas.

Explanatory note B - These figures are based on the December 31, 1958, estimates of the American Petroleum Institute, American Gas Association, and Canadian Petroleum Association. Allowance is made for expected moderate increases in 1959.

Explanatory note C - At the beginning of 1958, the original crude oil in place in drilled portions of known reservoirs in the United States totaled about 310 billion barrels. Cumulative production plus the proved reserves at that time amounted to approximately 28-1/2 percent of the estimated original oil in place. Adjusting this estimate to include Canadian deposits and additional acreage proved in 1958 and 1959, yields an estimate of approximately 344 billion barrels of crude oil originally in place, of which 280 billion barrels remain in the ground. To this

is added 20 billion barrels of natural gas liquids, derived from the estimated natural gas in-the-ground (line 3) by applying the natural-occurrence factor of approximately 60 barrels of NGL per million cubic feet of natural gas.

The estimate for natural gas in the ground is based upon the assumption that past extraction plus current proved reserves represent about 85 percent of the quantity originally in place.

Explanatory note D - The history of proved-reserve estimates indicates that extensions and revisions applicable to cumulative discoveries to a given time will more than equal the proved-reserve estimate at that time. Thus future extensions and revisions for fields now known should at least equal 41 billion barrels (line 2) of liquid hydrocarbons. Over the past decades extensions alone have accounted for slightly more than 60 percent of the total revisions and extensions. Use of this factor yields an estimate of about 25 billion barrels for future extensions to proved reserves, which was converted to petroleum-in-the-ground by assuming an average recovery factor of one-third.

In general, natural gas discoveries are not developed as rapidly as crude-oil discoveries because of the necessity for pipeline outlets and because of local over-supply. Accordingly, extensions to proved reserves of natural gas are potentially greater than for crude oil. Future extensions to reserves of known reservoirs were estimated at two-thirds the known quantity.

Explanatory note E - It was pointed out earlier that the volume of unexplored potentially productive rocks in the United States and Canada is roughly 10 times the volume explored thus far. The estimated amount of petroleum found so far is the sums of lines 1, 3, and 4. It seems unlikely that the average incidence of petroleum in the unexplored rocks is as great as in those explored so far; on the other hand, it seems unlikely to be as low as one-third, on the average, of that of the explored rocks. The rough estimates in line 5 are based on this general appraisal. The discovery prospects are better for natural gas and natural gas liquids than for crude oil, for increasingly greater relative quantities of the former are found with increasing average depth of exploration. Therefore a slightly more generous estimate was made for undiscovered natural gas.

Large additional quantities of petroleum and natural gas are present in both the explored and unexplored rocks, but are too thinly concentrated or in deposits too small or too difficult to produce to be considered in this appraisal. However, technologic progress in the future may render extraction of some of this quantity feasible.

Whether the quantities listed in line 5 will ever be discovered must also depend on the amount of exploratory drilling in the future, which in turn will depend upon economic factors.

Other Allied and Neutral Countries

Proved reserves of petroleum liquid hydrocarbons for the other regions shown on the map, Figure 1, are estimated to be 243.4 billion barrels as of January 1, 1960. This is approximately 75 times the current annual production. A ratio of proved reserves to annual production of 15 to 20 would be adequate, so that currently there is an abundant supply of petroleum liquid hydrocarbons in these regions.

Proved reserves of natural gas in these allied and neutral countries are estimated to be of the order of 80 trillion cubic feet, or about 40 times the current annual rate of utilization. Large but unknown quantities of natural gas produced with oil are wasted, particularly in the Middle East. Most natural gas deposits are in regions remote from markets. Thus far natural gas could not be transported to distant markets as could oil by tankers.

The problems involved in appraising not only the possible recoverable oil and gas in yet undiscovered oil and gas reservoirs, but also in appraising the total amounts of oil and gas actually present in such undiscovered deposits, have been discussed. It is apparent that much greater uncertainty would apply to any estimates of the total oil and gas in place in undiscovered deposits outside the United States and Canada. The ultimate amounts of oil and gas in place in the other allied and neutral countries conceivably could be from three to ten times the amounts listed in Table 6.

The figure of 940 billion barrels of recoverable oil in undiscovered deposits is about twice the first estimate of this type made in 1948, and current estimates will probably be increased as more geological data become available. These estimates are based on studies of the geological characteristics of the sedimentary basins of the world coupled with the past 100 years' experience in finding petroleum deposits under known geologic conditions in such basins. Similar estimates of the quantities of recoverable natural gas in undiscovered deposits, aggregating 3,000 trillion cubic feet, are more conservative than those for liquid petroleum hydrocarbons as it is probable that indeterminate quantities of natural gas produced with oil will continue to be wasted, rather than be recovered for use in the near future.

Table 6.--Estimated proved and undiscovered reserves of petroleum liquid hydrocarbons and natural gas in selected foreign areas (Jan. 1, 1960)

Geographic area	Recoverable petroleum liquid hydrocarbons		Recoverable natural gas	
	Proved reserves (billion barrels)	Undiscovered (billion barrels)	Proved reserves (trillion cu. ft.)	Undiscovered (trillion cu. ft.)
	(1)	(2)	(3)	(4)
Caribbean America	21.1	120	40	300
Other South America	2.0	80	10	250
Western Europe and Turkey	1.6	18	5	50
North Africa	7.9	80	5	200
Other Africa	0.1	12	0	50
Middle East	200.0	560	10	2,000
Far East	10.7	70	10	150
Australia and New Zealand	0.0	0	0	0
Totals	243.4	940	80	3,000

Sources and derivation of data: The principal source used in the foregoing tabulation is: Weeks, Lewis G., "Where Will Energy Come From in 2059," PETROLEUM ENGINEER, volume 31, No. 9, August 1959, pages A-24 to A-31. The data from this source have been supplemented and modified by data from WORLD OIL, International Outlook Issue, volume 149, No. 3, August 15, 1959, and from publications of the United Nations and the Organization for European Economic Cooperation.

Accuracy of data: The data in Column 1 on proved reserves of petroleum liquid hydrocarbons are comparable to similar statistics published by the American Petroleum Institute on the United States within a probable range of plus or minus 20 percent for most areas. For North Africa, the value shown is from Weeks and is believed to be realistic although it is 2 to 4 times greater than other published estimates. Recent major discoveries in this area render estimates of proved reserves transitory. Weeks is practically the only source for the estimates of recoverable oil in undiscovered deposits of petroleum hydrocarbons shown in Column 2. Weeks' data have been adjusted to correspond to the geographic areas listed. The data in Columns 3 and 4 on natural gas are order of magnitude only, as no definite world wide data are published.

Recoverable Petroleum and Natural Gas

The utilization of natural gas has been developed to a marked degree only in the United States and Canada. Other highly industrialized areas in the allied and neutral countries have not had access to large supplies of natural gas.

Historically the availability of natural gas has been a function of the availability of crude petroleum. Prices for natural gas in the United States and Canada have risen steadily for 15 years as it became available to more and more consumers through long distance transmission lines. No details are presented on recoveries and availability of natural gas with changing technologies and changing prices. Recoveries and availability of natural gas will be a major function of petroleum supply.

The relationship between price and production of petroleum is shown in Table 7. The responses shown have been computed by estimating new oil wells needed to achieve the production noted, estimating the associated total footage drilled, and estimating the total wellhead revenue from oil and gas associated with this footage drilled.

Historically the United States and Canada have had about a third more wells than are necessary to achieve the desired producing capacity and to prove reserves in the most economic manner. In Table 7 this excess of wells is presumed to have been eliminated by 1975. If the historical pattern of excess wells persists, production in 1975 and 2000 will be lower than the figures shown by about 10 percent at the low end of the price range and by about 20 percent at the high end. The 1975 and 2000 figures presume also that the 40-percent excess industry capacity described in the next section will be reduced to 10 percent.

Table 7.—United States crude petroleum production at alternative price levels and stages of technology

Millions of barrels of petroleum

Well price in 1959 Dollars	Technology		
	1959 Actual	1975 Expected	2000 Likely
3.00 a barrel	2,570	3,800	3,400
1/4 less (2.25)	2,400	3,300	3,000
1/4 more (3.75)	3,200	4,500	3,950
1/2 more (4.50)	3,400	5,300	4,500

As a measure of the effect of technology, it is estimated that if technology remains at its 1959 level 1975 production would be 10 percent less than otherwise; or stated differently, that a 25 percent higher price would be required to bring out equivalent production.

The oil resources of Caribbean America, North Africa, and the Middle East have not been studied in the detail given to oil studies in the United States and Canada, and the effects of technology and price cannot be forecast with the certainty associated with oil resources in the United States. Vast quantities of oil and gas will be available at near present prices from Caribbean America, North Africa, and the Middle East for years to come, beyond 1975. Technology will minimize any price increases and will increase recoveries.

Physical Capacity to Produce Petroleum and Natural Gas

The estimated crude oil production in the United States for 1960 is 2,701,000,000 barrels. The total crude oil productive capacity for the United States in 1960 is 3,660,000,000 barrels. Expected totals for the United States and Canada are 2,892,100,000 barrels produced, with a capacity of 4,058,200,000 barrels--i.e., 40 percent excess capacity.

For the rest of the allied and neutral countries the 1960 expected production is 3,630,000,000 barrels. Most of this will come of course from Caribbean-America and the Middle East. Excess productive capacity likewise is greatest in these two areas and is of the order of 30 per cent. This gives a capacity of about 4,720,000,000 barrels for 1960.

Total production for all nine areas in 1960 will be about 6,520,000,000 barrels. Productive capacity totals 8,780,000,000 barrels, or 35 per cent in excess of current utilization.

No problems are in sight for the transportation of petroleum. Pipeline capacities can be increased and new pipeline construction is underway. There is a very large excess of tanker transportation and this situation will continue for several years. A sizeable increase in the tanker fleet now is on the construction ways or planned, with scheduled delivery over the next 5 years equal to one-half the 1958 world tanker fleet capacity.

No serious problems exist for natural gas transmission in the United States and Canada, with expansion continuing. Natural gas utilization has not posed transportation problems of great magnitude in the rest of the allied and neutral countries. Sea transportation of natural gas as a liquid may mean the utilization of large quantities of now-wasted gas in Venezuela and the Middle East and the development of latent gas resources in North Africa.

Costs for finding and producing petroleum in the United States and Canada have been gradually increasing year by year and this trend is expected to continue. However, the industry has been able to expand capacity in recent years without a corresponding increase in the price of crude oil. The present industry replacement cost for crude oil in the United States is $3.38 per barrel of reported proved reserves. This includes all costs of exploration, drilling, production, and royalties but does not take account of future revisions in the reserve estimates. Production in the United States theoretically could be increased 100 per cent at that price at the present time if there were need for such an increase. In the rest of the major oil areas the replacement costs are less, along with production costs. An increase of 100 per cent in petroleum production in Caribbean America and the Middle East conceivably could be achieved at present prices, if there were a demand for the oil.

There is a finite limit to the petroleum and natural gas resources available for recovery from the earth, but as has been shown, the oil resources of the world are enormous. Production rates can be increased two, three, four, or more times in the future as demands increase. A possible ceiling on the rate of oil and gas production worldwide is not yet in sight. The peak in oil and gas production may not appear in the next 40 years.

OIL SHALE AND TAR SANDS

Problems of Appraising Oil Shale and Tar Sands Resources

The discovery of practically all the significant known occurrences of oil shale and bituminous sands has been the result of surface indications or outcroppings of the deposits. A few deposits have been found as the result of exploration or mining operations for other minerals, including the drilling of wells in search of oil and gas.

Since the comparative costs associated with the production and delivery of oil from oil shale or bituminous sands have been too high generally to make oil from such sources competitive with petroleum, natural gas, and coal, there has been no great incentive to obtain full data on potential oil yield and to define the extent of many oil shale and tar sands deposits. The oil shale deposits, being bedded, can be appraised accurately by costly but normal mapping and sampling. Tar sands deposits are generally less uniform and are more difficult to appraise accurately.

The tremendous oil shale deposits in Colorado in the United States, and the oil resources of the Athabasca tar sands of Alberta in Canada, have been delineated and characterized to a large extent from assays and studies of cores and drill cuttings recovered in the drilling of oil and gas wells. The existence of other tar sands deposits in the United States and in Venezuela in South America has been shown by recovery of similar oil well cores.

As technology provides new methods and instruments for locating and delineating all mineral resources, including fuels, these techniques will be applied, with suitable modifications, to the study of the oil shale and tar sands resources. It is not felt that future techniques will be developed for these latter resources significantly different to the appraisal techniques that will be applied to minerals and conventional fuels.

Technology of Production and Transportation

The three major steps in the conversion of solid oil shale into liquid hydrocarbon products are: 1) mining of the oil shale rock, 2) heating or retorting of the crushed and sized oil shale to convert the solid organic material (kerogen) to a high pour point (90°F.) shale oil, and 3) processing the shale oil into the desired products.

The oil shale industry predates the petroleum industry. The present small-scale operations in Scotland, South America, Spain, and Sweden have developed over a period of years and the operations do represent an advanced technology for small scale plants.

Conventional techniques specifically adapted to the oil shales of the United States have been used to develop a large scale, room-and-pillar mining method here. Many kinds of specialized equipment were used to allow a highly mechanized operation in large underground rooms.

Technology for the continuous, large scale retorting of the mined oil shale has been developed also in the last 15 years in the United States.

The crude shale oil produced by any efficient retorting method is not markedly different from many typical heavy crude oils, except for a high content of nitrogen compounds. In general, such crude shale oil is amenable to conventional petroleum refining processes. If the crude shale oil is to be turned into industry products at a point distant from the retorts, some processing is required at the retort site to reduce the viscosity and the 90° F. pour point.

The three major steps in the production of petroleum products from tar sands are: 1) mining of the sands, 2) separation of the heavy oil content from the unconsolidated sands, and 3) processing of the recovered oil by conventional methods to finished products.

There have been intermittent operations for utilization of tar sands for many years throughout the world. There are some such operations on a small scale today that are of a minor and local importance.

The mining of tar sands on a large scale presents no difficult problems. Strip mining is applicable, with stripping of a limited amount of overburden, for possible operations between now and 1975, although the sands in some cases may be sticky and

hard to handle. Present technology permits the use of very large conventional equipment, especially designed for the particular deposit and for the particular sequence of steps to be used.

The separation of the oil or bitumen from the sands can be accomplished in a number of ways: Washing by water, hot or cold; solvent extraction; direct heating or retorting; or separation by centrifugal force. All of these methods have been demonstrated on a pilot-plant scale and all have merit. The final choice will be guided by specific conditions imposed by an application at a particular site and time.

The processing of the oil recovered from tar sands presents no special problems. The oil is quite similar to many natural heavy crude oils. One problem has been the removal of the sand fines and silt normally remaining in the recovered oil. Present available methods seem to overcome this drawback. Where light crude oils are also available at a particular refinery, these light oils can be mixed with the bituminous sand oil to give a composite crude of the most desirable characteristics for refining.

Making a broad, general comparison with advances in synthetic rubber production catalytic cracking, and sea transport of oil in the past 15 years, costs for the overall production of oil from oil shale should be reduced by one-third by 1975 below the $3-a-barrel figure quoted on page 34 (in constant dollars). Included in this estimate is a credit to the full use of automation in mining, retorting, and processing operations. One major source of technologic advance will be the practical experience that will have been acquired from the operation of a number of full-scale oil shale plants expected to be built.

The most obvious product from the treatment of both oil shale and tar sands to yield energy fuels is liquid oil, convertible to liquid petroleum products. Not to be overlooked is the production of high B.t.u. gas directly from either oil shale or tar sands. The technology for conversion of oil to gas already is firmly established.

The same practical experience indicated as a technologic advancement available to oil shale exploitation applies equally well to the recovery of oil from tar sands on a large scale. Present technology is essentially equivalent today for both resources.

Another possible technical achievement is the lowering of costs associated with the mining of oil shale through the use of nuclear detonations in place of conventional explosives. The Atomic Energy Commission and the Bureau of Mines have under study a cooperative project with industry to determine the feasibility of shattering and fragmenting large quantities of oil shale by detonation of a nuclear device deep within an oil shale formation. If large quantities of the oil shale can be broken, a further experiment could be performed to determine if the broken oil shale could be retorted in place. Such procedures would eliminate the conventional mining, crushing, and transportation of the oil shale. The in-place retorting, if successful, would eliminate the construction of costly retorts, a major cost item in oil shale utilization.

Atomic energy also may become a factor in the recovery of oil from the Athabasca sand deposits. Under study now is a plan to detonate experimentally a nuclear device deep in these deposits. The objective here is to utilize the great heat content from a nuclear detonation to raise the temperature of large quantities of the oil and sand present in the Athabasca deposits. This Athabasca oil is unique in that its viscosity is permanently changed when the oil is heated to a temperature less than the boiling point of water. The change makes the oil more fluid. If this change can be effected economically underground by the heat released in an atomic explosion, the oil can be pumped from the ground through the conventional oil well. This would allow recovery of the vast quantities lying beneath one to two thousand feet of overburden.

As to the possible situation by the year 2000, the one certain conclusion is that science is now advancing at such an accelerated rate that there can be no specific prediction. In terms of the availability of energy fuels from both oil shales and tar sands, it is logical to visualize that such quantities will be available as are necessary to meet the localized demands limited by geography, transportation, and the availability of fuels from competitive sources of supply.

Resources of Oil Shale and Tar Sands

Oil shales are widely distributed throughout the world. The known higher grade parts of a number of deposits that have been mined in Allied European countries, in Africa, and Australia are relatively small. The commercially attractive portions of these deposits perhaps contain less than 10 billion barrels of oil equivalent, and are not important for purposes of this report.

For purposes of this study only two countries appear to contain sizeable resources of sufficient oil content and thickness to be of probable interest—the United States and Brazil. The oil shales of Colorado that average 25 gallons of oil per ton in beds at least 15 feet thick, represent in place more than 400 billion barrels of oil. Similar oil shales in Utah and Wyoming represent 120 billion and 12 billion barrels of oil, or a total for the three states of more than 532 billion barrels.

For Brazil the extent of the oil shale resources is not known with the certainty associated with the minimum figures for the United States. They are at least the equivalent of 300 billion barrels of oil in place.

The situation is analogous for tar sands. Tar sands occur widely throughout the world and their existence has been known for centuries, but the underground extent of the bituminous rock deposits is less predictable than the oil shale deposits. Deposits outside Canada now known are comparatively small or have not been explored and described in detail. Most are probably too small to be of significance in this present consideration. Information at hand is insufficient to estimate specific potential resources of some foreign deposits that may be large.

In the United States selected tar sand resources of Utah, Texas, and California are estimated to contain about 2 to 3 billion barrels of bitumen in near surface parts of the deposits. Numerous other bituminous rock deposits in the United States are not fully appraised. By extending these estimates to include deeper parts of appraised deposits, and to include other unappraised deposits based on present knowledge, the potential bitumen resources in these sands may eventually prove to be several times the amount of published detailed estimates. Weeks has recently estimated about 10 billion barrels of oil may be contained in U. S. deposits.

The Athabasca occurrence in Alberta in Canada has been moderately explored but much additional work has to be done to define the full extent of this vast deposit. These tar sands have been estimated to contain about 300 billion barrels of oil in the ground.

By extending the definition of oil shale resources to include material of lower oil content (15 gallon per ton oil shale, for instance), the estimates given above for oil shale perhaps can be more than doubled. From present knowledge and geological inferences, the combined total oil shale and tar sand resources, in place, including some inadequately appraised lower-grade deposits, are estimated to contain more than 3 trillion barrels of equivalent oil.

Recoverable Oil from Oil Shale and Tar Sands

The experimental work done to date has shown that oil from oil shale and tar sands can be produced at a price not significantly different from $3.00 per barrel, the present average crude oil price in the United States for domestic oil. A present deterrent to the initiation of commercial operations for the recovery of oil from shale or sand is the large excess petroleum productive capacity available in the United States. Another deterrent is the availability of imported crude oil at a price less than $3.00 per barrel. Still another deterrent is the unfavorable geographic location of the shale and sand deposits in respect to refineries and markets.

As indicated in a prior section, technology available in 1975 will allow a significant reduction in the cost of producing oil from shale or sand, as compared to the price of crude oil produced domestically. Oil from these two resources is expected to be produced in quantity after 1975, but the total availability will be limited by some of the deterrents listed above and by other considerations. In the case of shale oil production in the United States, the limiting factor will be a lack of water to support plants and people. Present water resources, supplemented by the construction of a number of costly reservoirs for storage, could support a shale oil industry producing 2 million barrels a day. Present considerations indicate a shale oil productive capacity of 80,000 barrels a day by 1975, followed by a gradual increase in capacity to 1 million barrels a day by the year 2000. If one considers only the amount of the resource, at least 50 billion barrels of oil could be recoverable from the Colorado shale deposits alone at competitive prices by 1975.

In Brazil some of the same considerations must be applied in assessing the availability of oil from shale with the technology available in 1975. No sizeable production is forecast for Brazil before 1975. Several plants with a total capacity of 50,000 barrels a day may be in operation in that year. This productive capacity should rise gradually to a million barrels a day in the year 2000. None of this is seen as available to any but local South America markets.

In Canada the development of oil production from the Athabasca tar sands is slowed by many of the same factors indicated for oil shale. In addition, most of the present and future expanding crude oil production in Canada is found south of the Athabasca deposits, at points closer to markets. The same picture is forecast for the development of oil production from these tar sands as has been indicated for oil shale. A small output of less than 100,000 barrels a day should be in existence by 1975. Capacity will increase to the million barrels a day level by the year 2000. Here again,

looking only at the resource base and 1975 technology, the Athabasca sands could yield at least 50 billion barrels of oil at competitive prices.

With our present knowledge, no significant production of oil from oil shale or tar sands is forecast elsewhere in the nine areas prior to the year 2000. There will be small operations, supplying localized needs, in many countries. These will not add to the supply for world markets.

It is sure that technology will have advanced so much in 40 years that continuing large supplies of oil can be made available from oil shale and from tar sands at most reasonable costs. Transportation technology will allow cheaper movement of such oil to consuming centers. The main consideration in predicting the status of an oil industry based on shale and sand is the necessity for such an industry. As our natural crude oil supplies diminish, with a continuing demand for energy, science and technology will be applied to the problem and solutions will be created.

Since it has been stated that oil can be produced from oil shale or tar sands at a price not significantly different from the present price of domestic crude oil--$3.00 per barrel--the effects of price changes on the availability of oil from shale and sand will be similar to the effects on crude oil availability now and for the next 40 years.

There is no practical ceiling to the year 2000 imposed by either resources or recoverability on production of oil from oil shale or from tar sands. A total capital investment of $40 billion--not a large sum in our future economy--would provide a daily oil production from oil shale and tar sands of over 10 million barrels. The question for the future in North America is not one of resource base or technology. It is simply a question of need.

SUMMATION OF RESOURCES

The following tables summarize the mineral fuel resources of the United States and allied and neutral countries in coal, petroleum, natural gas, oil shale, and tar sands. Totals are given in terms of conventional units for each commodity and in terms of an approximate B.t.u. equivalent.

Table 8. Coal Resources

Geographic area	Proved recoverable reserves		In place in discovered recoverable deposits		In place in all deposits	
	Million metric tons	Trillion B.t.u. equivalent	Million metric tons	Trillion B.t.u. equivalent	Million metric tons	Trillion B.t.u. equivalent
North America	215,000	6,200,000	430,936	12,445,432	1,592,802	46,000,122
Caribbean	2,000	58,000	4,133	119,361	19,379	559,666
South America	500	14,000	950	27,436	3,805	109,888
Western Europe	138,000	3,980,000	276,059	7,972,584	500,021	14,440,606
North Africa	-	-	5	144	20	578
Other Africa	19,000	548,000	37,955	1,096,140	69,830	2,016,690
Middle East	-	-	-	-	-	-
Far East	5,200	150,000	10,399	300,323	76,899	2,220,843
Australia	6,300	182,000	12,667	365,823	58,684	1,694,794
Total	386,000	11,132,000	773,104	22,327,243	2,321,440	67,043,187

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Table 9. Petroleum Resources

Geographic Area	Proved recoverable reserves Hydrocarbon liquids		In place in discovered deposits		In place in undiscovered deposits 2/	
	Billion barrels	Trillion B.t.u. equivalent	Billion barrels	Trillion B.t.u. equivalent	Billion barrels	Trillion B.t.u. ecuivalent
North America	41.0	237,800	300.0	1,740,000	3/ 1,500	8,700,000
Caribbean	21.1	122,380	1/ 63.3	367,140	360	2,088,000
South America	2.0	11,600	1/ 6.0	34,800	240	1,392,000
Western Europe	1.6	9,280	1/ 4.8	27,840	54	313,200
North Africa	7.9	45,820	1/ 23.7	137,460	240	1,392,000
Other Africa	0.1	580	1/ 0.3	1,740	36	208,800
Middle East	200.0	1,160,000	1/ 600.0	3,480,000	1,680	9,744,000
Far East	10.7	62,060	1/ 32.1	186,180	210	1,218,000
Australia	-	-	-	-	-	-
Total	284.4	1,649,520	1,030.2	5,975,160	4,320	25,056,000

1/ These figures are 3 times the proved reserves indicated in the first column. This conversion assumes a recovery experience similar to that in the United States.

2/ Except for North America, these figures are 3 times the indicated recoverable oil in undiscovered deposits shown in Table 6.

3/ The lower figure of the 1,500 to 2,500 range shown in Table 5.

undiscovered deposits shown in Table 6.

3/ The lower figure of the 1,500 to 2,500 range shown in Table 5.

Table 10. Natural Gas Resources

Geographic area	Proved recoverable reserves		In place in discovered deposits		In place in undiscovered deposits	
	Trillion cubic feet	Trillion B.t.u. equivalent	Trillion cubic feet	Trillion B.t.u. equivalent	Trillion cubic feet	Trillion B.t.u. equivalent
North America	280	308,000	350	385,000	1/ 3,000	3,300,000
Caribbean	40	44,000	40	44,000	300	330,000
South America	10	11,000	10	11,000	250	275,000
Western Europe	5	5,500	5	5,500	50	55,000
North Africa	5	5,500	5	5,500	200	220,000
Other Africa	-	-	-	-	50	55,000
Middle East	10	11,000	2/ 200	220,000	2,000	2,200,000
Far East	10	11,000	10	11,000	150	165,000
Australia	-	-	-	-	-	-
Total	360	396,000	620	682,000	6,000	6,600,000

1/ The lower figure of the 3,000 to 5,000 range shown in Table 5.

2/ Calculated on the basis of a minimum of 1,000 cubic feet per barrel of proved recoverable petroleum reserves.

Table 11. Oil Shale Resources

Geographic area	Proved recoverable reserves - shale oil		Equivalent shale oil in place in discovered deposits		Equivalent shale oil in place in all deposits	
	Billion barrels	Trillion B.t.u. equivalent	Billion barrels	Trillion B.t.u. equivalent	Billion barrels	Trillion B.t.u. equivalent
North America	50	290,000	532	3,085,600	1,000	5,800,000
Caribbean	1/	-	2/	-	3/	-
South America	50	290,000	300	1,740,000	600	3,480,000
Western Europe	1/	-	2/	-	3/	-
North Africa	1/	-	2/	-	3/	-
Other Africa	1/	-	2/	-	3/	-
Middle East	1/	-	2/	-	3/	-
Far East	1/	-	2/	-	3/	-
Australia	1/	-	2/	-	3/	-
Total	110	638,000	852	4,941,600	2,000	11,600,000

1/ A total of 10 billion barrels of recoverable oil is included in this column for the known appraised deposits in these areas.

2/ A total of 20 billion barrels of equivalent oil in place is included in this column for these areas.

3/ An estimate of 400 billion barrels equivalent oil in place in both known and undiscovered deposits is included in the total of 2,000 shown for this column.

deposits is included in the total of 2,000 shown for this column.

Table 12. Tar Sands Resources

Geographic area	Proved recoverable reserves of oil		Oil in place in discovered deposits		Oil in place in all deposits	
	Billion barrels	Trillion B.t.u. equivalent	Billion barrels	Trillion B.t.u. equivalent	Billion barrels	Trillion B.t.u. equivalent
North America	52.0	301,600	310	1,798,000	310	1,798,000
Caribbean	-		-		1/	
South America	-		-		1/	
Western Europe	-		-		1/	
North Africa	-		-		1/	
Other Africa	-		-		1/	
Middle East	-		-		1/	
Far East	-		-		1/	
Australia	-		-		1/	
Total	52.0	301,600	310	1,798,000	1,000	5,800,000

1/ An estimate of 690 billion barrels of oil in place in known and undiscovered deposits is included in the total of 1,000 shown for this column.

Table 13. Total Resources - Coal, Petroleum, Natural Gas, Oil Shale, and Tar Sands

Geographic area	Proved recoverable reserves Trillion B.t.u. equivalent	In place in discovered deposits Trillion B.t.u. equivalent	In place in all deposits Trillion B.t.u. equivalent
North America	7,337,400	19,454,032	67,723,122
Caribbean	224,380	530,501	3,388,806
South America	326,600	1,813,236	5,302,688
Western Europe	3,994,780	8,005,924	14,842,146
North Africa	51,320	143,104	1,755,538
Other Africa	548,580	1,097,880	2,282,230
Middle East	1,171,000	3,700,000	15,644,000
Far East	223,060	497,503	3,801,023
Australia	182,000	365,823	1,694,794
Total	1/ 14,117,120	2/ 35,724,003	3/ 122,756,347

1/ Includes 58,000 equivalent for 10 billion barrels of shale oil not detailed in areas.
2/ Includes 116,000 equivalent for 20 billion barrels of shale oil not detailed in areas.
3/ Includes 6,322,000 equivalent for 1,090 billion barrels of shale oil and oil from tar sands not detailed in areas.

ENERGY CONVERSION FACTORS

Energy Commodity	Energy Content (B.t.u.)	Per unit indicated
1. Bituminous coal	26,200,000	Net or short ton
2. Petroleum	5,800,000	Barrel of 42 U.S. gallons
3. Shale oil	5,800,000	Barrel
4. Tar sand oil	5,800,000	Barrel
5. Natural gas	1,100	Cubic foot
6. Natural gas liquids	4,620,000	Barrel

Note: All coals are assigned the B.t.u. content of bituminous coal. An average figure is used for all crude oils and the same B.t.u. content for crude oil is used for shale oil and oil from tar sands.

not detailed in areas.

B.t.u. Unit in Terms of Standard Commodity Units

1×10^{12} = 1 U. S. trillion = 1,000,000,000,000

1×10^{12} B.t.u. = 1 trillion B.t.u. = 1,000,000,000,000 B.t.u.

1×10^{12} B.t.u. coal = 38,168 net or short tons coal (2000 lb.)

1×10^{12} B.t.u. crude oil = 172,414 barrels crude oil

1×10^{12} B.t.u. natural gas = 909,090,909 cubic feet natural gas

1×10^{12} B.t.u. natural gas liquids = 216,450 barrels natural gas liquids

LETTER REQUEST TO FEDERAL POWER COMMISSION

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In addition, we would be appreciative if the Federal Power Commission could prepare for us an analysis or study of hydropower resources of the United States, its allies, and neutral countries, assuming various cost levels and assuming various degrees of technological development. To be consistent with other studies that are being made for us on other energy resources, the effect of costs at levels significantly above and below present levels should be assessed as well as the effects of technological development for the years 1975 and 2000 (that is, 15 and 40 years from now).

We have been assured that the Department of the Interior and the Corps of Engineers will be pleased to collaborate in this work. I understand that Dr. Lasky of the Department of the Interior has already discussed this with your staff and has furnished them with an outline for our oil study as a sample of the kind of information we are seeking.

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TRANSMITTAL LETTER FROM FEDERAL POWER COMMISSION

Further reference is made to your letter * * * requesting an analysis or study of the hydroelectric power resources of the United States and allied and neutral countries and the possibilities for the development of these resources to meet projected demands for the years 1975 and 2000.

Inclosed are two copies of a report prepared by the Commission's Bureau of Power, comprising the text and three tables, together with a map identifying the geographic areas adopted for the study. Additional copies of the report are available if desired.

We trust that the information furnished in this report is adequate for your purpose.

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FEDERAL POWER COMMISSION
Bureau of Power

Hydroelectric Power Resources of the United States and Allied and Neutral Countries
April 1960

Introduction

This report has been made pursuant to request, dated February 17, 1960, that the Joint Committee on Atomic Energy, United States Congress, be advised as to the hydroelectric power resources of the United States and allied and neutral countries, and the possibilities for the development of these resources to meet projected demands for the years 1975 and 2000, the forecasts to include consideration of the effects of technological improvements and changing economic conditions.

Identification of Geographic Areas

For this study the United States and allied and neutral countries have been divided into eight geographic areas shown in Fig. 1 and listed below.

North America
South America
Western Europe
Africa
Middle East
Southeast Asia
Far East
Australasia

These eight areas comprise a total area of 36,155,000 square miles. They have an aggregate population of 1,905,499,000 representing about 67 percent of the World's total. The countries comprising the geographic areas, together with the areas and populations of each, are shown in Table 1.

Basis of Estimates of Potential Hydroelectric Power

World statistics on hydroelectric power resources are deficient in that there is no regular source of statistics that is comprehensive as regards the different countries of the world; and such isolated statistics as are available from different sources are usually not comparable as to their documentation and validity. Many, but not all, countries publish from time to time information on their estimates of potential hydroelectric power using varying bases for

their estimates, thus making it difficult if not impossible to relate the data of one country to data of other countries. The World Power Conference has published bi-ennially a Statistical Yearbook containing data on the potential hydroelectric power resources of certain countries. Publication of this Yearbook has now been discontinued. The most recent yearbook available, the eighth in the series, was published in 1956. A major deficiency of this yearbook is the omission of so large a number of countries from the compilation. For example only a third of the approximately seventy-five countries covered by this study are listed in the yearbook. Hence, because of the many gaps in coverage, the yearbook does not provide an adequate source for the data needed for this study.

The U. S. Geological Survey has been publishing at intervals since 1921 figures showing, country by country, estimates of the total water power potential. The original compilation was based on published estimates made from existing data on rainfall and topography. These figures have been issued at about two or three-year intervals in Geological Survey Circulars, the latest being Circular 367, issued in December 1954. The figures have been kept up-to-date by the Geological Survey mainly by following hydroelectric power developments in published reports and by supplanting estimates of potential power by later estimates prepared in the countries themselves. This publication is the only known comprehensive compilation of potential water power available.

The estimates of potential water power compiled by the Geological Survey are based on power outputs with ordinary minimum flow and also with mean flow at project sites, assuming 100 percent efficiency. The effect of storage is disregarded except for constructed reservoir sites, the estimated potential water power being based on existing flows. Estimates of potential power based on mean flow are considered by the Survey to be quite reliable for the United States, Canada and most countries of Western Europe. They represent the amount of horsepower which is physically developable assuming mean flow of streams, gross head of sites, and 100 percent efficiency of plants. The estimates are considered by the Geological Survey to be considerably above the economically feasible power possibilities of a given country.

In the present study, the figures of potential power based on mean flow given in Circular 367 have been used as a basis for the estimates of available hydroelectric energy for the various countries. Adjustments were made in the data in an attempt to achieve conformity with the Federal Power Commission's estimates of undeveloped water power in the United States, which include projects of demonstrated economic feasibility as well as projects where physical conditions indicate engineering feasibility and promise at some time of economic feasibility. The Commission's estimates of undeveloped hydroelectric power, including the latest published in 1957, 1/ make

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1/ Hydroelectric Power Resources of the United States, Developed and Undeveloped, 1957, FPC-P-36.

allowance in the estimates for depletions by irrigation and other consumptive use, and assume that each site would be developed to achieve, in conjunction with the development of other sites, the best over-all development of the water resources of the river basin for power and other multiple uses.

The adjustment was made for the present study by applying a factor of 60 percent to the potential hydroelectric energy computed on the basis of the Geological Survey's estimated horsepower potential based on mean flow. This factor was selected partly to make allowance for the 100 percent efficiency on which the estimates were based and partly because the figures represented the total amount of power which is physically developable and which was considered to be, in general, much above the amount of power showing promise of ultimate economic feasibility.

Conditions vary so widely in the different countries that any over-all estimates of available hydroelectric power can be considered as being only approximate at best. The present hydroelectric development of a country, past rate of growth of developed hydroelectric power, economic conditions, degree of industrialization, thermal-electric power sources including nuclear power development, proximity of undeveloped water power sites to load centers, cost of developing hydroelectric power, multiple uses of water besides power, and numerous other factors would enter into making a close estimate of power potential available to meet projected demands. However, for the purpose of this study, which is to obtain in broad outline a picture of the hydroelectric power resources of the several areas, approximate estimates of the power potentialities of the individual countries, when taken in the aggregate, serve adequately to indicate from a long-range view the over-all potentialities of a geographical area and the amount of the resources available for possible future development.

Potential Hydroelectric Energy

Based on the data of potential water power by countries published in Geological Survey Circular 367, with adjustments made as explained earlier in the text, the estimated aggregate potential hydroelectric energy of the eight geographic areas covered by this study is about 10,190 billion kilowatt-hours annually. Allowance for a margin of error in this estimate should be made since the source data for countries such as South America, Africa and Asia, having over three-quarters of the total potential energy resources, are based on figures principally deduced from precipitation and topography and are therefore not as dependable as figures obtained from actual river basin surveys. The estimated potential hydroelectric energy for each geographic area, is summarized below. (See Table 2 and Fig. 1)

1. North America. This geographic area includes Canada, the United States, Mexico, the Central America countries and the West Indies, comprising an aggregate area of about 8.4 million square miles. Its estimated potential hydroelectric energy is 1,331.5 billion kilowatt-hours, amounting to 158 thousand kilowatt-hours per square mile. The United States, including Alaska and Hawaii, has the largest amount of potential hydroelectric energy, totaling 572.4 billion kilowatt-hours. Canada's potential energy is 408.3 billion kilowatt-hours, while the combined potential hydroelectric energy of Mexico and the Central American countries totals 335 billion kilowatt-hours. The West Indies account for 15.8 billion kilowatt-hours.

2. South America. The countries of South America, with an aggregate area of about 6.9 million square miles, have a total hydroelectric energy potential of 2,456.9 billion kilowatt-hours, amounting to 357 thousand kilowatt-hours per square mile. Brazil has the largest total amount of potential hydroelectric energy, with 945.7 billion kilowatt-hours. The next two countries in order of amount of potential energy are Colombia and Peru, with totals of 392.4 and 215.9 billion kilowatt-hours, respectively. The combined hydroelectric energy potential of these three countries with the largest individual amounts of potential power, accounts for about 63 percent of South America's total.

3. Western Europe. The countries comprising Western Europe, with a total area of about 1.5 million square miles, have potential hydroelectric energy aggregating 670.9 billion kilowatt-hours, amounting to 462 thousand kilowatt-hours per square mile. Norway, with potential hydroelectric energy totaling 116.6 billion kilowatt-hours, is the only country in Western Europe having a total potential exceeding 100 billion kilowatt-hours. Sweden, Italy, and France approach this figure with energy potentials of 93.8, 92.5, and 91.2 billion kilowatt-hours, respectively.

4. Africa. The African countries included in this geographic area, with an aggregate area of approximately 10.1 million square miles, have the largest total amount of potential hydroelectric energy of any of the geographic areas covered in this study, totaling about 3,319.7 billion kilowatt-hours, or 328 thousand kilowatt-hours per square mile. Sixty percent of Africa's potential hydroelectric energy is concentrated in the Belgian Congo (which occupies the greater part of the Congo River basin), with 941.4 billion kilowatt-hours, French Africa, which includes French Equatorial Africa, French West Africa, and the French Cameroons, with 636.8 billion kilowatt-hours, and Angola, with 411.4 billion kilowatt-hours.

5. Middle East. Countries in the Middle East, with an aggregate area of 2.7 million square miles, have a total hydroelectric energy potential of 94.1 billion kilowatt-hours, amounting to 34 thousand kilowatt-hours per square mile. Afghanistan and Turkey are the leading countries

in amount of potential hydroelectric energy, with totals of 39.2 and 27.7 billion kilowatt-hours, respectively.

6. Southeast Asia. The countries comprising Southeast Asia, with an aggregate area of 3.2 million square miles, have a total hydroelectric energy potential of 1928.2 billion kilowatt-hours, amounting to about 61 thousand kilowatt-hours per square mile. Burma leads in amount of potential energy, with 409.8 billion kilowatt-hours. India and Indonesia have, respectively, 452.5 and 450.8 billion kilowatt-hours and the countries of Cambodia, Laos, and Viet Nam have a combined energy potential of 352.6 billion kilowatt-hours. The combined energy potential of these several named countries having the largest amounts of potential energy in the geographic area, makes up 90 percent of the area's total potential hydroelectric energy.

7. Far East. Japan, South Korea, Taiwan, and the Phillipines, with an aggregate area of 0.3 million square miles, have a total potential hydroelectric energy of 193.0 billion kilowatt-hours, amounting to about 620 thousand kilowatt-hours per square mile. The potential energy is concentrated in Japan where there are 119.4 billion kilowatt-hours, representing 62 percent of the total for the area.

8. Australasia. This geographic area, comprising Australia, Tasmania, and New Zealand, with an aggregate area of 3.1 million square miles, has a total potential hydroelectric energy of 195.5 billion kilowatt-hours, amounting to 63 thousand kilowatt-hours per square mile. Australia and Tasmania, together, have the major portion of the total potential, amounting to 150.2 billion kilowatt-hours.

Present Developed and Undeveloped Hydroelectric Power

For a number of years the Federal Power Commission has compiled data on the installed electric generating capacity and annual electric energy production of all countries of the world. This information is obtained from published material received from many sources and from dispatches of United States consular agents. In some instances reported data are not available and in those cases estimates, based upon the best data available, are included. The latest compilation shows that the installed electric generating capacity of the United States and allied and neutral countries totalled 374.6 million kilowatts in plants of all types (hydro and thermal) at the end of 1958. Of this total 121.7 million kilowatts, or 32.5 percent, were installed at hydroelectric plants with a total annual energy production of approximately 533 billion kilowatt-hours. This production represented about 5 percent of the estimated total potential hydroelectric energy of the United States and allied and neutral countries. (See Table 2 and Fig. 1.)

The extent to which electric power has been developed in individual countries varies greatly. To a large degree, the magnitude of these developments and the types of developments have been brought about by the energy resources available for the production of power. However in many countries where the hydro electric energy resources are plentiful very little electric power is produced. In these cases, financial problems and low economic development appear to be the principal deterents to the use of available energy sources for the development of electric power. In twenty of the countries having potential hydroelectric energy resources there were no hydroelectric installations in 1958. By contrast, in many countries hydroelectric plants were the predominant source of electric power, notably such countries as Canada, Japan, Italy, Sweden, Norway, Spain, and Switzerland. The status of hydroelectric development in the individual geographic areas, as of December 31, 1958, is summarized in the following paragraphs.

1. North America. This geographic area had a total developed hydroelectric generating capacity of 48.6 million kilowatts, with an annual generation of 239.3 billion kilowatt-hours, amounting to 18 percent of the area's potential hydroelectric energy. The United States led in amount of installed capacity with 30.1 million kilowatts and a corresponding annual generation of 143.9 billion kilowatt-hours energy, representing 25 percent of the hydroelectric energy potential of the United States. Canada had installations totaling 17.0 million kilowatts capacity, with an annual generation of 90.2 billion kilowatt-hours, representing 22 percent of Canada's hydroelectric energy potential. Mexico and the Central American countries accounted for nearly 3 percent of the total installed capacity in the area and 2 percent of the hydroelectric energy produced.

2. South America. A comparatively small amount of hydroelectric capacity was installed in South America, totaling 4.9 million kilowatts, which generated 20.5 billion kilowatt-hours of electric energy, amounting to only 0.8 percent of South America's potential hydroelectric energy. Nearly two-thirds of South America's installed hydroelectric capacity was in Brazil where 3.1 million kilowatts were installed, with a corresponding annual generation of 13.5 billion kilowatt-hours.

3. Western Europe. The largest total installation of hydroelectric generating capacity of all the areas under study was in Western Europe, amounting to 51.4 million kilowatts, with an annual generation of 193.3 billion kilowatt-hours. This generation was 28.8 percent of Western Europe's potential hydroelectric energy. Italy, with an installed capacity of 12.0 million kilowatts and an annual generation of 35.3 billion kilowatt-hours, amounting to 38 percent of the country's potential hydroelectric energy, was the leading country in amount of installed capacity. France was second in amount of installed capacity, with a total installation of 9.1 million kilowatts having an annual generation of 32.2 billion kilowatt-hours, amounting to 35 percent of the

country's potential hydroelectric energy. Sweden followed in third place in amount of installed capacity, with a total installation of 5.8 million kilowatts, and a corresponding annual generation of 28.9 billion kilowatt-hours, representing 31 percent of the country's potential energy. Norway, Switzerland and Spain each had aggregate installations of slightly over 4 million kilowatts capacity, and the combined annual generation of the three countries was about 55 billion kilowatt-hours. Western Germany's hydroelectric plants, with a total installed capacity of 3.2 million kilowatts, had an annual generation of 13.2 billion kilowatt-hours.

4. Africa. Only five countries in Africa had existing hydroelectric plants. Their combined installed capacity was 1.5 million kilowatts, with an annual generation of 5.0 billion kilowatt-hours, amounting to 0.15 percent of the geographic area's potential hydroelectric energy. The largest installation was in the Belgian Congo, with 0.7 million kilowatts capacity having an annual generation of 2.8 billion kilowatt-hours. Morocco had 0.4 million kilowatts installed capacity, generating 0.8 billion kilowatt-hours energy.

5. Middle East. In the Middle East countries, Turkey, Lebanon, and Syria alone had hydroelectric installations, with an aggregate capacity of 0.3 million kilowatts and a corresponding annual generation of 0.9 billion kilowatt-hours, amounting to 1.0 percent of the potential hydroelectric energy of the Middle East. Turkey's installed capacity was 0.2 million kilowatts, with an annual generation of 0.7 billion kilowatt-hours electric energy.

6. Southeast Asia. There was only a small amount of installed capacity in the countries comprising Southeast Asia, totaling 1.6 million kilowatts, with an annual generation of 6.1 billion kilowatt-hours, amounting to 0.3 percent of the area's potential hydroelectric energy. Hydroelectric installations were confined to India, Indonesia, Pakistan, and Ceylon. India, with 1.2 million kilowatts installed capacity, and an annual generation of 4.9 billion kilowatt-hours, accounted for three-quarters of the area's installed capacity.

7. Far East. About 29.5 percent of the hydroelectric energy potential in the Far East countries was utilized at existing hydro plants having an aggregate installed capacity of 11.3 million kilowatts, and an annual generation of 57.0 billion kilowatt-hours, amounting to 29.5 percent of the area's potential hydroelectric energy. Japan accounted for 10.5 million kilowatts installed capacity, or 93 percent of the area total, and 53.5 billion kilowatt-hours energy.

8. Australasia. Existing hydroelectric plants in this area had installations totaling 2.1 million kilowatts capacity with a corresponding annual generation of 8.7 billion kilowatt-hours, amounting to 4.5 percent of the potential hydroelectric energy of the area. The

total capacity was about equally divided between Australia (including Tasmania) and New Zealand. Australia's annual generation totaled 3.3 billion kilowatt-hours while 5.4 billion kilowatt-hours were generated at the New Zealand plants.

Relation of Developed Hydroelectric Power to Total Power Supply

The total developed hydroelectric capacity accounted for 32.5 percent of the 374.6 million kilowatts total hydro and thermal electric generating capacity of the area covered by this study, as of December 31, 1958. (See Table 3.) The total hydroelectric energy production accounted for 35.0 percent of the 1,521.2 billion kilowatt-hours total, hydro and thermal, production, averaging 798 kilowatt-hours per capita. The Far East had the largest percentage of total capacity in hydroelectric plants, amounting to 57.7 percent of the 19.6 million kilowatts total generating capacity of the area. The hydroelectric energy production of the area accounted for 65.9 percent of the 86.5 billion kilowatt-hours total, hydro and thermal, production, averaging 587 kilowatt-hours per capita. North America, with the largest total generating capacity of 186.1 million kilowatts, had 26.1 percent of the total capacity installed in hydroelectric plants. The hydroelectric energy production of the area accounted for 28.5 percent of the 839.9 billion kilowatt-hours total, hydro and thermal, production, the largest production of any area, averaging 3312 kilowatt-hours per capita. Western Europe, with a total generating capacity of 136.6 million kilowatts, had 37.6 percent of the total capacity installed in hydroelectric plants. The hydroelectric energy produced by these plants accounted for 41.4 percent of the 466.6 billion kilowatt-hours total, hydro and thermal, production averaging 1460 kilowatt-hours per capita. Of the remaining five areas, each with total generating capacities of less than 10 million kilowatts, South America had the largest percentage of developed hydroelectric capacity, amounting to 50.0 percent of the 9.8 million kilowatts total generating capacity. The hydroelectric energy production of South America accounted for 49.8 percent of the 41.2 billion kilowatt-hours total, hydro and thermal, production, averaging 311 kilowatt-hours per capita. The Middle East had the lowest per capita, hydro and thermal production, amounting to 27 kilowatt-hours.

The percentage of the total generating capacity in the study area provided by hydroelectric plants decreased about 4 percent for all eight areas during the 10-year period 1948-1958, although there was an increase of 93 percent in total hydroelectric installations during the period. The combined total installed generating capacity of both hydroelectric and thermal-electric plants increased 113 percent. Decreases in percentages of total generating capacity provided by hydroelectric plants occurred during the 10-year period in North America and the Far East while the percentage in Western Europe remained the same. In these three areas the increases in installed hydroelectric capacity during the 10-year period amounted to 82 percent in North America, 66 percent

in the Far East, and 104 percent in Western Europe, while the corresponding percentage increases in total generating capacity in the same areas amounted to 126, 75, and 103 percent, respectively. In other areas, where hydroelectric development has been relatively small, - the aggregate installed capacity of these areas being not quite 10 percent of the aggregate installed capacity of North America, Western Europe, and the Far East - the percentage of total generating capacity provided by hydroelectric plants showed an increase in the 10-year period, amounting to as much as 10 percent in the Middle East and 8 percent in Africa.

Future Development of Hydroelectric Power

The rate at which hydroelectric power is developed and the amount of the potential that may ultimately be developed depends upon many factors. A sound program to develop hydroelectric power must recognize the many other purposes which may be served through the development of water and land resources. The pressures of expanding population and of improved living standards make essential the most effective conservation and utilization of water resources, not only in areas where water is at present a critical resource but in all areas which may become critical in the future. Primary considerations must be given to the maximum development of streams for supplying domestic, industrial, and irrigation water requirements. Other beneficial purposes, such as navigation, recreation, and power production must of necessity have a lower order of priority. Flood control will be inherent in the control of many streams for these purposes.

The general objective of the multiple-purpose concept of developing river basins is the full use of natural resources through the economically sound, comprehensive, integrated development of material wealth - water, land, forest, and mineral - including the conservation and enhancement of exhaustible resources and the greatest yield of replaceable resources. In the United States, the multiple-purpose concept of developing river basins has been widely practiced and it has been found under this concept of basin development that many hydroelectric plants which are economically infeasible when considered alone have become feasible when considered in combination with other uses. Although rough estimates can be made of the total capacity installation that may be required to develop the undeveloped hydroelectric potential of a river basin, these estimates must be revised from time to time in the light of changing conditions as a country's power systems are developed to serve the rapidly growing loads.

The best ultimate use of hydroelectric resources cannot be realized in most instances unless the hydro is used in combination with thermal-electric resources. The amount of thermal-electric capacity required to

fully develop the hydroelectric potential of a given river basin will depend on such factors as the hydraulic characteristics of the river flow, the amount of river regulation provided and the seasonal and annual characteristics of its use, the magnitudes and characteristics of the system load to be served, the proximity of the hydroelectric power plants to the system loads and the relative cost of producing thermal power. In undeveloped countries the rate of development of hydro and thermal power depends primarily upon the speed and degree of industrial development.

With the advent of nuclear power, concern has been expressed as to the possibilities of an adverse effect of future installation of nuclear plants on the development of hydroelectric power. However, inasmuch as nuclear plants, as they become competitive with other sources of power, will normally be designed for base load operation at high capacity factors, hydroelectric plants with ample pondage or with reservoir storage capacity will be especially valuable under such conditions for peaking purposes. Combined with either base load nuclear power plants or thermal electric plants they can provide a dependable and economical source of power.

In this connection, pumped storage hydroelectric development have been utilized extensively in Western Europe and they are receiving increased recognition in other areas, as in the United States, as a source of economical peaking power. At such development surplus energy from thermal or nuclear plants can be used to pump water from a tailwater pond to a high-level reservoir for re-use through the hydraulic turbine. Development of the two-way pump-turbine, and the adoption of nuclear power plants as a primary source may well give impetus to this trend.

Projections of Developed and Undeveloped Power to 1975 and 2000

Estimates of the developed and available undeveloped hydroelectric power 15 to 40 years in the future must of necessity be only approximate. As indicated in the foregoing section, the future rate of growth of developed power and the amount of available undeveloped power in any area depend on many factors. From information available it is not possible to make any definite prediction as to these factors. Information is available regarding growth in amount of developed hydroelectric capacity over the 10-year period 1948 to 1958 for the individual countries. Use of this 10-year rate of growth makes possible a straight line projection of installed capacity from 1958 to the years 1975 and 2000. The estimates of future development obtained by this method are apt to be low because of the many countries where power development is virtually nil or has been retarded in the past and, in the course of the next 15 to 40 years, may be expected to experience accelerated growth. Hence the straight-line projection, an entirely statistical method, may be

considered as indicating a lower limit of the amount of power to be developed in future years.

The estimated annual generation corresponding to the estimated installed capacities in 1975 and 2000 was obtained by assuming that for hydroelectric power developed after 1958 the installations would be made at a plant factor of 50 percent. Average plant factors in 1958 for the several geographic areas ranged from 34 percent in the Middle East area to 56 percent in North America, and to 58 percent in the Far East, where Japan is the dominant country. For all the countries the average plant factor was 50 percent.

The projection to 1975 and 2000 for the eight geographic areas are described in the following paragraphs. (See Table 2 and Fig. 1.)

1. North America. In North America the estimated annual hydroelectric generation in 1975 is 402.7 billion kilowatt-hours, amounting to 30.2 percent of the potential hydroelectric energy of 1331.5 billion kilowatt-hours, and leaving 928.8 billion kilowatt-hours of undeveloped hydroelectric energy. The estimated installed capacity in 1975 is 85.9 million kilowatts. By the year 2000, it is estimated that developed power will reach an annual generation of 642.3 billion kilowatt-hours of 48.2 percent of the potential hydroelectric energy, leaving undeveloped energy at that time amounting to 689.2 billion kilowatt-hours. The estimated installed capacity in 2000 is 140.6 million kilowatts.

By 1975 the developed power in the United States will have reached an estimated annual generation of 244.2 billion kilowatt-hours, leaving 328.2 billion kilowatt-hours of undeveloped hydroelectric energy. The estimated 53.0 million kilowatts capacity to be installed by 1975 agrees closely with the Federal Power Commission's estimate made in June 1959 of hydro capacity desirable in combination with installed thermal capacity to supply expected loads in 1975. By 2000 the hydroelectric power installations are estimated to have an annual generation of 392.2 billion kilowatt-hours, leaving an estimated 180.2 billion kilowatt-hours of undeveloped hydroelectric energy. The estimated installed capacity in 2000 is 86.8 million kilowatts.

Canada, by 1975, will have installations estimated to have an annual generation of 148.5 billion kilowatt-hours, leaving undeveloped hydroelectric energy of 259.8 billion kilowatt-hours. The estimated installation in 1975 is 30.3 million kilowatts. By the year 2000, the estimated annual generation will amount to 233.9 billion kilowatt hours and the remaining undeveloped hydroelectric energy will amount to 174.4 billion kilowatt-hours. The estimated installed capacity in 2000 will have risen to 49.8 million kilowatts, a figure which appears to be in accord with the growth anticipated by the Water Resources Branch,

Department of Northern Affairs and National Resources, Canada, as reported in the Canada Yearbook for 1959.

2. South America. In South America, which has had a slow rate of growth in hydroelectric installations, the estimated annual generation in 1975 is 38.9 billion kilowatt-hours, or 1.6 percent of the potential hydroelectric energy of 2456.9 billion kilowatt-hours, leaving undeveloped hydroelectric energy of about 2418.0 billion kilowatt-hours. The estimated installed capacity is 9.1 million kilowatts. By the year 2000, the estimated annual generation is 66.1 billion kilowatt-hours, or about 3 percent of the potential hydroelectric energy. The estimated undeveloped hydroelectric energy is 2390.8 billion kilowatt-hours. The estimated installed capacity is 15.3 million kilowatts. Since both the present development and the 10-year growth are small, the actual growth by 1975 and 2000 could be considerably larger than indicated by straight line projection. However, inasmuch as the potential hydroelectric energy is large, there is little or no likelihood of a shortage in available energy occurring by 2000 whatever the growth in power requirements may be.

3. Western Europe. Western Europe, with a present utilization of 28.8 percent of its potential hydroelectric energy, may be expected to reach 58.0 percent utilization by 1975 and 84.1 percent by 2000. The projected annual generation in 1975 is 389.2 billion kilowatt-hours, with an installed capacity of 96.1 million kilowatts. The estimated undeveloped hydroelectric energy in 1975 is 281.7 billion kilowatt-hours. By the year 2000 it is estimated that the total hydroelectric installation will generate annually 564.0 billion kilowatt-hours of electric energy, with an installed capacity of 135.9 million kilowatts leaving undeveloped hydroelectric energy of 106.9 billion kilowatt-hours. The estimates of installed capacity and annual generation for 1975 are slightly lower than the 1975 forecasts made by Electricity Committee of the Organization for European Economic Cooperation for installed capacity and production in the countries in Western Europe. Inasmuch as the Committee reports that most of the economical sites in Western Europe are gradually being exhausted and the best sites for run-of-river plants have been used up, there is the possibility that the future rate of development of undeveloped sites will be lower than heretofore.

4. Africa. In Africa which at present has only a small amount of installed capacity, the estimated annual generation in 1975 is 13.8 billion kilowatt-hours, amounting to 0.4 percent of the total potential hydroelectric energy of 3319.7 billion kilowatt-hours, leaving undeveloped hydroelectric energy of 3305.9 billion kilowatt-hours. The estimated installed capacity in 1975 is 3.5 million kilowatts. By the year 2000 the estimated annual generation is 26.2 billion kilowatt-hours or 0.8 percent of the potential energy, leaving 3293.5 billion kilowatt-hours of undeveloped hydroelectric energy. The installed capacity in 2000 is 6.3 million kilowatts. There are countries in Africa which at

present have no hydroelectric plants and are not considered in this statistical analysis as having any developments in the future. It may be expected however that in some of the countries developments will actually be made which will add substantially to the estimated total. Also, in view of the low present development and the small past rate of growth, the future growth may be considerably higher than shown.

5. Middle East. Although the several countries in the Middle East geographic area have small amounts of potential hydroelectric power, only three countries thus far have hydroelectric plants. The estimated growth in these three ccuntries will make the area's installed capacity in 1975 only 0.7 million kilowatts, with an annual generation of 2.9 billion kilowatt-hours, or 3.1 percent of the total potential hydroelectric energy of 94.1 billion kilowatt-hours. The growth by the year 2000 will raise the installed capacity to an estimated 1.5 million kilowatts, generating annually 6.2 billion kilowatt-hours, or about 7 percent of the potential hydroelectric energy, leaving undeveloped hydroelectric energy of about 87.8 billion kilowatt-hours.

6. Southeast Asia. Southeast Asia is another area which has seen but a little development of its power resources. By 1975 the estimated installed capacity will be 3.3 million kilowatts, with an annual generation of 13.6 billion kilowatt-hours, or less than one percent of the potential energy of 1928.2 billion kilowatt-hours, leaving undeveloped hydroelectric energy of 1914.6 billion kilowatt-hours. The estimated installed capacity in 2000 will amount to 5.7 million kilowatts with an annual generation of 24.1 billion kilowatt-hours, slightly over one percent of the potential energy, leaving undeveloped hydroelectric energy of 1904.1 billion kilowatt-hours.

7. Far East. In the Far East, the estimated annual generation in 1975 is about 90.8 billion kilowatt-hours, or 47 percent of the potential hydroelectric energy of 193.0 billion kilowatt-hours, leaving undeveloped hydroelectric energy of 102.2 billion kilowatt-hours. The estimated installed capacity in 1975 is 19.0 million kilowatts. By 2000 the estimated annual generation is about 129.8 billion kilowatt-hours, or 67.3 percent of the potential hydroelectric energy, leaving undeveloped hydroelectric energy of 63.2 billion kilowatt-hours. These figures represent essentially the estimated growth of hydroelectric development in Japan, which accounts for over 90 percent of presently installed hydroelectric power in the Far East.

8. Australasia. In Australasia, the estimated annual generation in 1975 is 17.9 billion kilowatt-hours, with an installed capacity of 4.2 million kilowatts. The annual generation is 9.2 percent of the potential hydroelectric energy of 195.5 billion kilowatt-hours, leaving

undeveloped hydroelectric energy of 177.6 billion kilowatt-hours. In year 2000 the estimated installation is 7.1 million kilowatts with an annual generation of 30.6 billion kilowatt-hours, representing 15.7 percent of the potential hydroelectric energy, and leaving undeveloped hydroelectric energy of about 164.9 billion kilowatt-hours.

Factors Affecting Cost of Future Hydroelectric Development

As previously indicated the rate at which hydroelectric power is developed and the amount of the potential that may ultimately be developed depends upon a number of factors, such as the needs and uses of water for various purposes, the plans that may be formulated to develop a country's water resources, and, also the costs of hydroelectric power as well as the costs of alternative power supply.

Although it is possible to estimate, within reasonable limits, the possibilities of future hydroelectric development and to give some indication of the expected rate and amount of eventual development, it is not possible with any degree of accuracy to indicate the probable cost of hydroelectric power developed at some distant date. A number of factors influence the determination of hydroelectric power costs and the significance of cost data.

The need for and the extensive use of electric power goes hand in hand with industrial development, education, and the general over-all advancement of living standards. Development of power, particularly in the case of outstanding hydro sites, may precede and so create nearby industrialization. In the more highly developed countries such projects in general have already been developed, while in the less highly developed countries this is not true.

Most of the remaining hydroelectric potential in the more highly developed countries will be built as "peaking" capacity to supplement other kinds of capacity, a substantial amount of which is thermal. In the less developed countries the situation is reversed and a large percentage of the hydro that could be developed will for many years be the principal source of power. The passage of time will eventually alter this situation. Generally, the power used for peaking has a greater monetary value than power used in the base of the load or at system load factor. Hence there is justification for greater expenditure for the installation of peaking capacity. This, however, is not intended to detract in any manner from the basic value of the energy component.

Hydroelectric projects are characterized by having comparatively high capital costs and resulting high fixed charges but relatively low operating costs since there is no cost for fuel, which accounts for about 75 percent of the annual operating costs of thermal power and

tends to rise in price. Thus hydroelectric plants may have investment costs two or more times the cost per kilowatt of installed capacity of thermal-electric plants and still be competitive.

One aspect of the cost of hydroelectric development is the land inundated by reservoirs, the cost of which may be particularly important in highly developed countries. This problem is a man-made obstacle arising to a large extent from the ever-increasing population which demands more intensive land utilization. The cost of reservoir lands is steadily increasing as a percentage of the total project cost in highly developed countries like the United States. There are already instances in the United States where, for recently constructed projects, the land costs run up to as much as 1/3 of the total project cost. Aside from the valuations placed on valley land for general usage there are the relocation problems, particularly of railroads and highways. Historically, railroads, have generally followed the valleys and have blocked many otherwise feasible projects. Today the problem is more intensified by the similar practice in highways.

Many of the undeveloped countries will not be faced with such problems for many years to come. However they will be faced with the financing problems stemming from the essential industrial development as well as the hydroelectric project cost.

Technological improvements in general construction methods used in building hydroelectric projects, involving less man-power and more mechanization, have been most beneficial in holding down construction costs. It may be expected that there will be further improvements in construction methods. Hydroelectric power is frequently developed as a part of multiple-purpose projects, requiring that costs be allocated among the various purposes, thus reducing the construction cost chargeable to power of dams and reservoirs used jointly for other purposes. The present high efficiency of the hydraulic turbine, slightly over 90 percent, results in an over-all plant efficiency of considerably better than 80 percent. Little more can be expected in the reduction of costs by the improvement of hydroelectric plant efficiencies.

Since the cost of thermal power is used as a measure of value of hydroelectric power, in most cases, the technological improvement of thermal plants affects the utilization of hydroelectric power. The present top over-all efficiency of the thermal plant utilizing the steam turbine is just now approaching 40 percent. It is believed that by 1975 the best efficiencies will be about 45 percent. In the following 25 years there may be another 5 percent or slightly larger increase through technological progress, principally in the field of metallurgy.

The remarkable thing about the conventional thermal capacity is that the cost per kilowatt of construction has, relatively, been held down despite continuing inflation since World War II. Technological improvements in design and construction have resulted in increasingly larger generating units and other features that tend to reduce the unit cost.

It would be expected that changes in the general price levels would not significantly affect the future development of hydroelectric power vis-a-vis other sources of power to meet future in reases in power loads. The effects of such changes would normally be distributed somewhat evenly across the economy and apply equally to hydroelectric plants and to alternative thermal-electric plants. Sharply declining prices would usually occur in periods of widespread economic distress during which power demands would decline and new capacity installations, hydro or thermal, would be curtailed. On the other hand, sharply rising prices during inflationary periods should result in accelerated power demands that could be met either by hydro or thermal installations.

On the whole, therefore, it is to be expected that the same relative economic advantages that exist today with respect to thermal and hydro power in relation, one to the other, will be present in the future.

FEDERAL POWER COMMISSION
Bureau of Power

United States and Allied and Neutral Countries
Geographic Areas and Countries
with
Areas and Population

Country	Area Thousand Sq. Mi.	Population Thousand
North America		
Canada	3,851	17,154
Central America	211	11,160
Mexico	760	31,426
United States (incl. Alaska and Hawaii)	3,610	174,905
West Indies	4	18,881
Totals	8,436	253,526
South America		
Argentina	1,079	20,256
Bolivia	416	3,273
Brazil	3,288	62,725
Chile	286	7,200
Colombia	440	13,522
Ecuador	116	3,890
Guiana (3 divisions)	148	535
Paraguay	157	1,638
Peru	514	10,213
Uraguay	72	2,700
Venezuela	352	6,320
Totals	6,868	132,272
Western Europe		
Austria	32	7,000
Belgium	12	9,000
Denmark	17	4,525
Finland	130	4,373
France	213	44,500
Great Britain and North Ireland	94	51,600
Greece	51	8,150
Ireland (Irish Free State)	27	2,853
Italy	117	47,635
Luxembourg	1	320

Country	Area Thousand Sq. Mi.	Population Thousand
Western Europe (cont'd)		
Netherlands	13	11,173
Norway	125	3,526
Portugal	35	8,980
Spain	196	29,662
Sweden	173	7,415
Switzerland	16	5,185
Western Germany	96	54,375
Yugoslovia	99	18,397
Totals	1,447	319,669
Africa		
Algeria	853	10,324
Angola	481	4,354
Belgian Congo	905	13,437
Ethiopia	350	19,500
French Africa (Equatorial, West, and Cameroons)	2,957	26,692
Ghana	92	4,763
Kenya	225	6,261
Liberia	43	2,750
Libya	679	1,092
Madagascar	241	4,913
Morocco	172	10,400
Mozambique	298	6,170
Nigeria	373	31,800
Rhodesia Federation	478	7,261
Sierra Leone	28	2,500
Sudan	968	10,000
Tanganyika	363	8,453
Tunisia	48	3,800
Uganda	94	5,680
Union of South Africa	473	14,418
Totals	10,121	194,560

Country	Area Thousand Sq. Mi.	Population Thousand
Middle East		
Afghanistan	250	12,000
Egypt	386	24,532
Iran	628	18,945
Iraq and Saudi Arabia	1,045	13,038
Israel, Lebanon, Syria, Trans-Jordan	121	8,975
Turkey	297	24,797
Totals	2,727	102,287
Southeast Asia		
Burma	262	20,054
Cambodia, Laos, Viet Nam	305	33,000
Ceylon	25	9,165
India	1,222	397,540
Indonesia	736	85,500
Pakistan	365	85,635
Thailand and Malaya	251	27,353
Totals	3,166	743,747
Far East		
Japan	143	91,760
Philippines	116	23,000
South Korea	38	22,655
Taiwan (Formosa)	14	9,851
Totals	311	147,266
Australasia		
Australia and Tasmania	2,975	9,846
New Zealand	104	2,276
Totals	3,079	12,122
Totals for 8 areas	36,155	1,905,449

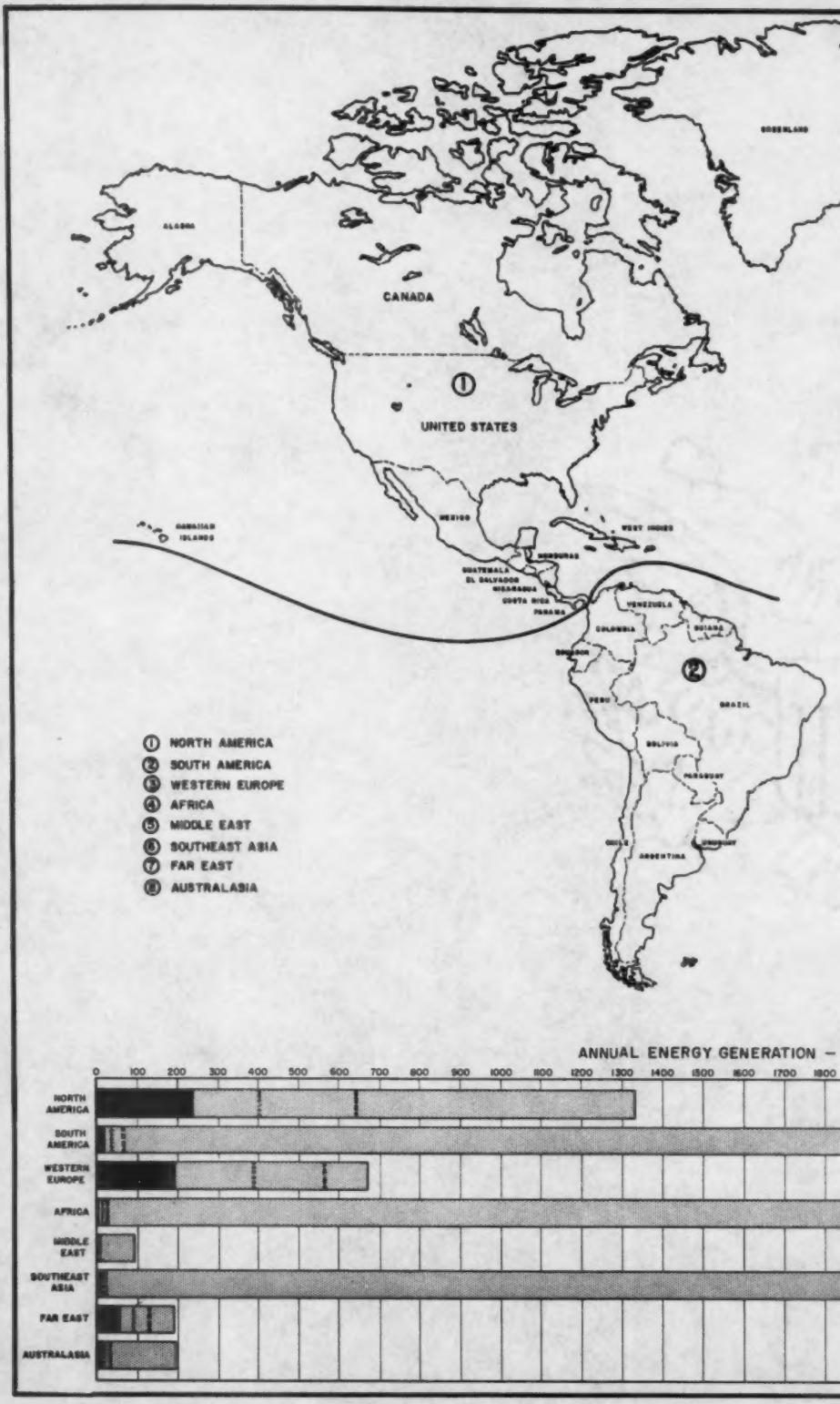
FEDERAL POWER COMMISSION
Bureau of Power

Total Potential Hydroelectric Energy
and
Developed and Undeveloped Hydroelectric Power,
Actual for 1958 and Projections for 1975 and 2000
in the
United States and Allied and Neutral Countries

Geographic Area	Potential Hydro Energy (Developed and Undeveloped) Billion Kwh	1958 Conditions — Developed Hydro: Annual Generation 1958 Billion Kwh	Ratio: 1958 Generation / Potential Per cent	Installed Capacity 1958 Million Kwh	Average Plant Factor Percent	Undeveloped Hydro Energy Billion Kwh
North America	1,331.5	239.3	18.0	48.6	56	1,092.2
South America	2,456.9	20.5	0.8	4.9	48	2,436.4
Western Europe	670.9	193.3	28.8	51.4	43	477.6
Africa	3,319.7	5.0	0.2	1.5	38	3,314.7
Middle East	94.1	0.9	1.0	0.3	34	93.2
Southeast Asia	1,928.2	6.1	0.3	1.6	44	1,922.1
Far East	193.0	57.0	29.5	11.3	58	136.0
Australasia	195.5	8.7	4.5	2.1	47	186.8
Totals	10,189.8	530.8	5.2	121.7	50	9,659.0

1/ Assumes installations at 50% plant factor for hydro power developed after 1958.

1975 Projection				2000 Projection			
	Developed Hydro				Developed Hydro		
Annual Generation 1975 Billion Kwh	Ratio: 1975 Generation / Potential Per cent	Installed Capacity 1/ 1975 Million Kw	Undeveloped Hydro Energy Billion Kwh	Annual Generation 2000 Billion Kwh	Ratio: 2000 Generation / Potential Per cent	Installed Capacity 1/ 2000 Million Kw	Undeveloped Hydro Energy Billion Kwh
402.7	30.2	85.9	928.8	642.3	48.2	140.6	689.2
38.9	1.6	9.1	2,418.0	66.1	2.7	15.3	2,390.8
389.2	58.0	96.1	281.7	564.0	84.1	135.9	106.9
13.8	0.4	3.5	3,305.9	26.2	0.8	6.3	3,293.5
2.9	3.1	0.7	91.2	6.2	6.6	1.5	87.9
13.6	0.7	3.3	1,914.6	24.1	1.2	5.7	1,904.1
90.8	47.0	19.0	102.2	129.8	67.3	27.9	63.2
17.9	9.2	4.2	177.6	30.6	15.7	7.1	164.9
969.8	9.5	221.8	9,220.0	1,489.3	14.6	340.3	8,700.5


GREENLAND
ALASKA
CANADA
UNITED STATES
MEXICO
HAWAIIAN ISLANDS
WEST INDIES
HONDURAS
GUATEMALA
EL SALVADOR
NICARAGUA
COSTA RICA
PANAMA
VENEZUELA
COLOMBIA
GUIANAS
ECUADOR
PERU
BRAZIL
BOLIVIA
PARAGUAY
CHILE
ARGENTINA
URUGUAY
① NORTH AMERICA
② SOUTH AMERICA
③ WESTERN EUROPE
④ AFRICA
⑤ MIDDLE EAST
⑥ SOUTHEAST ASIA
⑦ FAR EAST
⑧ AUSTRALASIA
ANNUAL ENERGY GENERATION –
0 100 200 300 400 500 600 700 800 900 1000 1100 1200 1300 1400 1500 1600 1700 1800
NORTH AMERICA
SOUTH AMERICA
WESTERN EUROPE
AFRICA
MIDDLE EAST
SOUTHEAST ASIA
FAR EAST
AUSTRALASIA

ENERATION – BILLION KILOWATT-HOURS

1600 1700 1800 1900 2000 2100 2200 2300 2400 2500 2600 2700 2800 2900 3000 3100 3200 3300 3400 3500

LEGEND
DEVELOPMENT AT
1958 1975 2000
TOTAL POTENTIAL

FIGURE 1

L ENERGY GENERATION – BILLION KILOWATT-HOURS

1400 1500 1600 1700 1800 1900 2000 2100 2200 2300 2400 2500 2600 2700 2800 2900 3000 3100 3200 3300 3400 3500

LEGEND
DEVELOPMENT AT
1958 1975 2000
TOTAL POTENTIAL

FEDERAL POWER COMMISSION
BUREAU OF POWER

HYDROELECTRIC POWER RESOURCES OF THE UNITED STATES AND ALLIED AND NEUTRAL COUNTRIES

IDENTIFICATION OF GEOGRAPHIC AREAS AND DISTRIBUTION OF HYDROELECTRIC ENERGY RESOURCES, TOTAL POTENTIAL, ACTUAL DEVELOPMENT IN 1958, AND PROJECTED DEVELOPMENT IN 1975 AND 2000.

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Table 3

FEDERAL POWER COMMISSION
Bureau of Power

Capacity of Developed Generating Plants
and
Corresponding Production of Electric Energy
For Hydroelectric and Thermal - Electric Plants
United States and Allied and Neutral Countries

Developed Power - December 31, 1958

Geographic Area	Installed Capacity				Energy Generation				Kilowatt Hours per Capita
	Hydro		Thermal	Total	Hydro		Thermal	Total	
	Capacity Million Kw	Percent of Total	Capacity Million Kw	Capacity Million Kw	Generation Billion Kwh	Percent of Total	Generation Billion Kwh	Generation Billion Kwh	
North America	48.6	26.1	137.5	186.1	239.3	28.5	600.6	839.9	3,312
South America	4.9	50.0	4.9	9.8	20.5	49.8	20.7	41.2	311
Western Europe	51.4	37.6	85.2	136.6	193.3	41.4	273.3	466.6	1,460
Africa	1.5	20.3	5.9	7.4	5.0	16.6	25.1	30.1	155
Middle East	0.3	10.0	2.7	3.0	0.9	8.6	9.6	10.5	103
Southeast Asia	1.6	27.6	4.2	5.8	6.1	30.2	14.1	20.2	27
Far East	11.3	57.7	8.3	19.6	57.0	65.9	29.5	86.5	587
Australasia	2.1	33.3	4.2	6.3	8.7	33.2	17.5	26.2	2,161
Totals	121.7	32.5	252.9	374.6	530.8	35.0	990.4	1,521.2	798

FREE WORLD ENERGY, PETROLEUM, AND NATURAL GAS OUTLOOK

Prepared for the Review Group by a Task Force on the Basis of Industry Interviews

FOREWORD

Estimates have not been prepared of the effect of technological changes or projected cost/price relationships, since any forecasting of these factors is extremely questionable and could well be misleading in appraising the future contributions of either nuclear or conventional energy sources.

One particular estimate might possibly be misinterpreted. Current proved reserves of liquid hydrocarbon in the United States have been estimated to be 65 billion barrels. Organizations such as the American Petroleum Institute have generally estimated these reserves at 35 to 40 billion barrels. Disagreement with the more generally recognized estimates is not intended. Reserves of 65 billion barrels are available in reservoirs which have been discovered to date in the United States. However, this volume of reserves has not yet been completely developed. The volume of reserves which have been completely defined by development drilling probably correspond to the 35 to 40 billion barrels estimate. However, in this case it is preferable to consider those reserves which exist in known reservoirs as being "proven," in order to place the estimates of domestic reserves on the same basis as the estimates of foreign reserves.

INTRODUCTION

This memorandum covers projections of free world energy requirements together with an assessment of the probable participation of petroleum and natural gas in meeting energy needs and an appraisal of the adequacy of petroleum and natural gas reserves to meet anticipated demands. In this study detailed consideration has been given to projections to 1975 with much more general treatment for the period 1975–2000. It is felt that beyond 1975 forecasting either overall energy requirements or the share of total energy demand which will be met from various sources is subject to so wide a margin for error that such forecasts should be treated in very general terms. As an overall comment on energy demand forecasting, there has been no attempt to make adjustments attributable to long-range price/cost relationships or the effect of technological development on these factors.

OUTLOOK FOR ENERGY DEMAND, 1955–75

Various techniques may be employed in making long-range energy demand forecasts. These include extension of historical trend data, correlation by relating energy consumption to some economic factors that can be readily projected and analysis of end-use of fuels in major consuming sectors. All of these techniques have been tested and used in varying degrees in preparing this forecast of free world energy requirements to 1975 and all are subject to reservations and uncertainties.

This is particularly true in many foreign areas where availability of reliable historical data on either fuel use or consuming units may be quite limited. Technological changes (e.g., railroad dieselization) can also make for substantial and unpredictable variation in requirement patterns for particular fuels. Finally, an entirely unforeseeable determinant of energy use can be government planning, restrictive action on certain fuels, etc.

Table I attached shows actual free world energy demands in quadrillions of B.t.u.'s for 1955 and projections at 5-year intervals between 1955 and 1975. Also shown are forecasts for petroleum and natural gas and the share participation of these fuels in the total energy picture. These data are summarized below:

Free world energy requirements—Petroleum and natural gas demand

	Actual 1955	Estimated			
		1960	1965	1970	1975
Total energy demand, quadrillion B.t.u.'s	79	94	111	130	151
Petroleum demand:					
Millions of barrels	5,288	6,814	8,221	9,645	11,180
Percent share of total energy	39	42	43	43	43
Natural gas demand:					
Billions of cubic feet	9,447	13,603	16,285	19,832	22,868
Percent share of total energy	12	14	15	16	16

These projections result in a growth rate in total free world energy demand of 3.5 percent/year, 1955–65, with a slightly slower rate of increase—3.2 percent/year—projected for the decade 1965–75. Over the postwar period, 1946–59, free world energy consumption has grown at an average rate of 4.2 percent annually.

Petroleum is at present the free world's principal supplier of energy and in the postwar era petroleum and natural gas together have supplied more than 80 percent of the growth in free world energy demand. It will be noted that the forward projections contemplate a continuing growth in the share for natural gas, though at a somewhat slower rate than in the past, while petroleum's share continues to increase over the next decade and then levels off. These growth patterns result from studies of fuel end-use in the various areas of the free world.

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Table I also shows a breakdown of energy, petroleum, and natural gas projections by various important areas of the free world. Abroad, Europe shows the most rapid gains for petroleum in share of the total energy market. Natural gas use in Free Europe is forecast to increase about fivefold, 1955–75, but still contributes only about 2 percent of the total energy requirement by 1975.

The projections for the U.S. result in somewhat slower growth rates than those discussed for the free world, i.e., 3.1 percent per year 1955–65 and 2.8 percent per year 1965–75. Nevertheless, the United States accounts for over 40 percent of the growth in free world energy demand between 1955 and 1975. Petroleum remains the principal source of energy supply in the United States. Natural gas continues to gain in share of total energy, though not as rapidly as in the postwar era to date, when use of natural gas was being extended to virtually every major center of population and industry in the country.

1975–2000

As mentioned previously, projecting energy requirements beyond 1975 is felt to be so precarious that no attempt has been made to do so by areas or end-use sectors, or to predict the percentage participation for various fuels. Continuation of very rapid gains in energy use is anticipated for the Free Foreign area where an enormous potential will still exist for very rapid per capita energy growth in the underdeveloped countries. In the United States long-term projections of population and industrial growth indicate that energy demand might be expected to grow by about 50 percent between 1975 and 2000. Overall, one might look for total free world energy requirement to grow by about 70 percent over the final quarter of the century.

PETROLEUM AND NATURAL GAS RESOURCES

Despite the approximately 60 percent increase in free world and U.S. energy demands anticipated over the next 15 years, and the fact that petroleum and natural gas are expected to maintain or increase their position in contributing the principal share of these energy needs, it is confidently expected that sufficient reserves of petroleum and natural gas are or will be made available to meet the indicated demand. Table II attached shows estimates of the current free world proved reserves of petroleum and natural gas as of the end of 1959. The volumes of liquid hydrocarbon shown are somewhat larger than the "booked" reserves, usually quoted, but they are felt to be more consistent and more realistic, particularly for comparison with estimates of foreign reserves. While not all of these reserves can be produced from present wells, they are producible from presently known reservoirs. It is interesting to compare the current proved reserve estimates for the important producing areas with those contained in the Report of the Panel on the Impact of the Peaceful Uses of Atomic Energy, January 1956, as shown below:

Proved reserve estimates—Petroleum and natural gas

	Liquid hydrocarbon (billion barrels)		Natural gas (trillion cubic feet)	
	Current	January 1956 report	Current	January 1956 report
United States	65	33	261	212
Other Western Hemisphere	38	34	[1] 83	63
Middle East	240	230	[1] 231	62
Other Eastern Hemisphere	22	7	50	7
Total free world	365	306	625	344

[1] Most of this gas is dissolved in oil and is available only as the oil is produced.

In considering these estimates of proved reserves it is well to emphasize again that, as pointed out by Wallace Pratt in the January 1956 Report:

> The term—(proved reserves)—means that part of the reserves already proved by drilling which is recoverable by methods currently in use and under current economic conditions. Proved reserves represent working stocks or inventory only.

Looking at the comparison of reserves by various areas as currently estimated with those given in the previous report, it will be noted that total Free World reserves of liquid hydrocarbon are estimated at 365 billion barrels, as of December 31, 1959, or about 20 percent higher than the figures previously used as of December 31, 1954. Most of this additional quantity is in the higher estimate for the United States, and in this connection it should be noted that recently published estimates by the Joint Committee on Reserves of the American Petroleum Institute and the American Gas Association place proved liquid hydrocarbon reserves at about 38 billion barrels year end 1959. As indicated above it is felt that the API/AGA reserve estimates are very conservative and furthermore are not comparable with the reserve estimates shown for the rest of the world. There has been some upward revision in proved reserve estimates for the Middle East but most of the increase in reserves for the balance of the Eastern Hemisphere is due to recent discoveries in North Africa.

Regardless of the estimating basis used, however, it is significant that the current estimates of Free World proved hydrocarbon reserves as of the end of 1959, are at least 30 billion barrels or 10 percent higher than the figures published previously for the end of 1954. In the United States even the API/AGA estimate is about 10 percent higher than the previous value. The gain in reserves on hand has been achieved despite petroleum consumption of nearly 30 billion barrels for the Free World and about 16 billion barrels in the United States over this five-year period.

With regard to natural gas reserves, about half of the substantial upward revision shown is due to more recent estimates of tremendous natural gas reserves (for the most part dissolved in oil) in the Middle East. In 1956, Middle East gas resources were very sketchily defined and it is now felt that the figure previously used was far too low. Even without the Middle East revision, however, the gain in Free World natural gas proved reserves is about twice total natural gas

consumption during the years 1955–59, while in the United States the reserve increase has been just about equal to consumption.

In summary, therefore, the Free World petroleum and natural gas industry is in a stronger proved reserve position today than at the time of the 1956 report despite the rapid growth in consumption during the intervening years.

Table III shows the current estimates of total economically recoverable Free World resources of liquid hydrocarbons and natural gas. These again are somewhat higher than the estimates appearing in the 1956 report and are based upon projections of future drilling activity, success in finding oil, etc. As previously stated, these estimates represent volumes known to be recoverable by current producing techniques and are probably conservative. To quote again from the 1956 report:

> Petroleum engineers confidentially expect improved techniques greatly to increase recoveries in the future. A smaller proportion of the oil originally in place in the reservoir will be left there when producing operations are completed.
>
> Improvements are certain to be developed in both exploration and recovery techniques. These will come as a result of better comprehension of geological processes and the nature of petroleum and its accumulations; as a result of mechanical refinements and inventions which will make possible more precise measurements of pertinent characteristics of the earth's crust, together with more efficient methods of drilling; and as a result of better methods of recovery, yielding higher percentages of the total oil and gas content of natural reservoirs. Better drilling techniques will result in higher discovery rates making possible the discovery and economic recovery of accumulations now economically unrecoverable.

OIL SHALE AND TAR SANDS

The two major sources of liquid hydrocarbons, other than petroleum, are impregnated shales and sandstone. These impregnations are not in liquid form, and their extraction requires extensive treatment. For this reason, neither source is in large scale, economic production. Both oil shales and tar sands are relatively common in sediments, worldwide. However, a single notable occurrence of each type is so large, that it far overshadows all others.

The world's largest reserve of high grade oil shale is in the Tertiary Green River formation of Colorado, Utah, and Wyoming. Recent estimates of oil in place in this deposit vary from 1 to 1.5 trillion barrels. This volume is contained only in those portions of the formation which would yield more than 11 gallons of oil per ton of rock.

Presently known methods should provide the recovery of some 200 billion barrels of oil from the Green River shales. Small scale research plants have been constructed to produce shale oil, but as yet, the economics will not permit large scale development.

Vast additional supplies are located in lower grade "ore," in the same general area but it is doubtful if the development of these will ever be economic or indeed, necessary. There is estimated to be an additional 1 trillion barrels of shale oil located in very low grade oil shales which underlie large areas of the Eastern United States, but in all probability this supply will never be exploited.

Weeks[1] estimates that there are 10 trillion barrels of shale oil located outside the United States, but the vast majority of this is also

[1] Weeks, L. G., address to AAPG, Wichita, Kans., Oct. 28–30, 1959.

located in very low grade shale. Small scale commercial development of oil shale has progressed for a number of years in Scotland, Scandinavia, Spain, Africa, Germany, and Czechoslovakia, but it is unlikely that this volume will ever be significant.

By far the world's largest potential supply of oil from tar sands is located in the Athabaska River region of Alberta, Canada. Recent estimates of the oil in place there agree on about 300 billion barrels, with some 35 billion barrels now thought to be recoverable. Here too, small scale pilot plant operations have been carried out, but it is unlikely that any significant volume of tar sand oil production will be developed in the near future. The several tar sand deposits in the U.S. are estimated to contain some 2 billion barrels of oil, but only about 200 million barrels are now thought to be recoverable. Some development of these deposits is underway but anticipated volumes are very small. Known tar sand reserves elsewhere in the world probably don't exceed 10 billion barrels, with no development anticipated.

ABILITY OF ESTIMATED RESERVES TO MEET FORECAST REQUIREMENTS

The above discussion projects Free World demand growth for petroleum 1960–1975 such that cumulative consumption over this period would be on the order of 130 billion barrels. This is less than half of currently estimated Free World proved liquid hydrocarbon reserves and only about 10 percent of estimated total liquid hydrocarbon resources. For natural gas there is a similar relationship of proved reserves to projected demand and the ratio of total resources is even more favorable.

In the United States the estimated cumulative consumption of oil and natural gas 1960–1975 is about equal to the current estimate of domestic proved reserves and about one-fourth the estimated volumes of total domestic resources. The ratio of resource availability to consumption is of course vastly increased if deposits of oil shale and tar sands are taken into account.

Thus it can be concluded that estimated Free World reserves of petroleum and natural gas are certainly adequate to meet requirements forecast to 1975. This confidence is based upon four important factors.

1. Presently booked reserve estimates are conservative.
2. They are based on the recovery of only about one-third of the oil in place in known reservoirs.
3. Vast volumes of sediments in present producing areas have not been explored.
4. Tremendous areas of the Free World's basins are totally, or only very slightly explored.

Even beyond 1975 the probabilities are that continuing exploration efforts and improved technology will make sufficient supplies of oil and gas available to meet demands for many years. In addition, the huge unexploited reserves of shale and tar sands will be available to help supply the world's fuel needs when the technology of recovering oil from these deposits becomes more fully developed and their production, as a source of energy, becomes economically attractive. At this point, therefore, it can be said that there are no reasonable grounds for predicting a shortage of hydrocarbon fuels within the foreseeable future.

APRIL 7, 1960 (Revised July 6, 1960)

TABLE I

FREE WORLD ENERGY REQUIREMENTS - 1955-1975

	Total Energy Quadrillion BTU's	Petroleum		Natural Gas	
		Millions of Barrels	Percent of Total Energy	Billions of Cubic Feet	Percent of Total Energy
UNITED STATES					
1955	40.5	3,088	44.6	8,920	22.8
1960	46.3	3,584	45.2	11,850	26.5
1965	55.0	4,091	43.5	14,550	27.4
1970	63.0	4,559	42.3	17,100	28.1
1975	72.0	5,076	41.3	19,410	27.9
CANADA					
1955	3.3	235	41.7	150	4.9
1960	4.0	307	45.6	380	9.6
1965	4.8	383	46.4	635	13.1
1970	5.8	477	47.9	870	14.9
1975	6.8	559	48.2	1,100	16.2
OTHER WESTERN HEMISPHERE					
1955	3.7	453	76.6	169	5.1
1960	4.6	609	77.5	273	6.2
1965	5.8	756	75.7	450	8.1
1970	7.4	934	73.8	682	9.7
1975	9.2	1,142	72.7	960	11.0
FREE EUROPE					
1955	22.5	897	22.1	174	0.7
1960	26.0	1,437	30.6	364	1.3
1965	29.9	1,889	34.9	444	1.4
1970	33.6	2,178	35.8	738	2.2
1975	37.7	2,474	36.2	865	2.3
OTHER FREE EASTERN HEMISPHERE					
1955	9.3	615	38.6	34	0.4
1960	12.7	877	40.4	136	1.1
1965	15.9	1,102	40.5	306	2.0
1970	20.2	1,497	43.3	442	2.3
1975	25.0	1,929	45.1	533	2.2
TOTAL FREE WORLD					
1955	79.1	5,288	38.8	9,447	12.3
1960	93.6	6,814	42.1	13,003	14.3
1965	111.4	8,221	42.6	16,385	15.1
1970	130.0	9,645	42.8	19,832	15.7
1975	150.7	11,180	42.8	22,868	15.7

TABLE II

PROVED RESERVES - PETROLEUM AND NATURAL GAS

December 31, 1959

	Liquid Hydrocarbon Billions Barrels	Natural Gas Trillions Cu.Ft.
Western Hemisphere	103	344
United States	65	261
Other North America	8	33
South America	30	50 *
Eastern Hemisphere	262	281
Western Europe	2	19
Middle East	240	231 *
Africa & Far East	20	31
Free World	365	625

* Most of this gas is dissolved in oil and is available only as the oil is produced.

TABLE III

TOTAL RESOURCES OF OIL AND GAS

	Liquid Hydrocarbon Billions Barrels	Natural Gas Trillions Cu.Ft.
United States	240	1,000
Rest of Free World	1,100	4,000
Total Free World	1,340	5,000

STAFF NOTE.—As further background information on the world petroleum situation the Review Staff has prepared a brief note, "The Price of Fuel Oil to Power Stations in Europe," based upon intensive discussions with U.S. and foreign experts in the petroleum industry.

THE PRICE OF FUEL OIL TO POWER STATIONS IN EUROPE

THE TREND IN PRICES

It is difficult to estimate price levels for so long a period ahead as ten years. They reflect the interplay of many market forces, which may differ from place to place as well as from year to year. In particular, market prices vary with such factors as the intensity of competition, the size of contracts, the freight element in the price at point of user and the degree to which the consumer outlet is one for which a fuel can command an efficiency or other premium. Any estimate must therefore be based on certain broad assumptions which are likely to hold good.

Since the market for oil is essentially international, one relevant factor conditioning the price for fuel oil in Europe is the price at which imports from other important refining centers are available. At current price/freight levels the c.i.f. price in North West Europe for heavy fuel imported from the Caribbean is about $2.75 per barrel. In some European areas and for some types of business, particularly large contract business, local surpluses and the resultant competition for outlets has forced selling prices below the levels appropriate to the international market. Current inland selling prices for normal "run of the mill" business range between $2.50–4.50 per barrel (40¢–70¢ per million B.T.U.'s).

It is anticipated that over the next several years, in Europe and worldwide, there will be surpluses of oil, refining capacity and transport. These surpluses will tend to exert a downward pressure on prices in both international and local markets.

Under these circumstances, one must expect that broadly speaking, over the next ten years, prices for fuel oil in Europe for normal "run of the mill" business will not be higher than at present, and may well be lower.

The price of fuel oil to power stations is in the broad proportion of 75% of delivered prices for the normal type of business indicated above. This is partly because sales to power stations generally involve large tonnages (with convenient methods of delivery) and partly because this is a highly competitive market for all fossil fuels. It is reasonable to assume that this present broad ratio will be maintained and it is therefore concluded that fuel oil prices in the power station market will lie between about $2–3 per barrel (30¢–50¢ per million B.T.U.'s).

Atomic power might be generated in Western Europe at a fossil fuel parity rate of 52–56¢ per million B.T.U.'s or about $3½ per bbl. This level is above the range of prices at which fuel oil and indeed all fossil fuels are likely to be sold to power stations.

HIGH COST AREAS

High cost fuel areas in the United States might be defined as those in which fuels were priced above 35¢ per million B.T.U.'s ($2.2 per bbl. oil equivalent). This definition is not, however, applicable to Europe. For both economic and political reasons Europe is likely to remain a coal-based economy for some time. European coal is relatively more expensive than fossil fuels in the U.S. The range of fossil fuel prices in Europe is of the order of 30–70¢ per million B.T.U.'s (about $2–4.5 per bbl.). Compared with this range the fuel oil prices estimated above cannot be considered high.

There are two reasons why it is perhaps unrealistic to talk of high cost areas for fuel oil—and indeed for all fossil fuels—in relation to atomic power in Europe.

1. Freight differentials within Europe tend to be smaller than within the United States.

2. Atomic power is unlikely to be competitive even in the late 1960's except for large base-load stations. The amount of fuel oil or coal consumed by large thermal stations is such as to attract a competitive price. It is unlikely therefore that there will be significant areas suitable for nuclear power where fossil fuels will be high in price. On the other hand there are one or two areas where, for particular reasons, fuel oil prices are likely to be low, notably Italy, where a surplus of fuel oil is likely to persist and Sweden, which is subject to additional pressure of competition from Russia.

STAFF NOTE.—As additional background on petroleum utilization, the Review Staff has prepared a brief memorandum, "Oil Fired Thermal Power Stations in Western Europe in 1965," based upon discussions with authoritative European manufacturing representatives.

OIL FIRED THERMAL POWER STATIONS IN WESTERN EUROPE IN 1965

CAPITAL COST

The engineering cost of a 300 MW. station with one or two generating sets constructed specifically for oil firing should not be more than $110/kw; it could be as low as $105/kw.

(If provision is made for conversion to coal firing at a later date the cost might be about $125/kw. A dual-fired station might cost about $140/kw. About 12–15% should be *added* to these figures to cover consultants' fees, purchase of the site, interest during construction and contingencies.)

THERMAL EFFICIENCY

An operating efficiency of 36½% (38½% under optimum conditions) is attainable by 1965 in oil fired stations given the current state of technical development. It is assumed that direct cooling would be used and that the preheat steam temperature is 1050° F. (If metallurgical developments enabled temperatures to be raised towards 1200° F., the operating efficiency may be expected to approach 40%.)

29TH APRIL 1960.

WORLD TANKER OUTLOOK

Note by the review staff: As further information on world petroleum supply the table below has been extracted from Loren F. Kahle's (Standard Oil Co. of New Jersey) article in the December 28, 1959, issue of the Oil and Gas Journal.

ESTIMATED POTENTIAL INDUSTRY TONNAGE POSITION

	Average year T–2 equivalent				
	1959	1960	1962	1964	1966
Available tonnage:					
Total, beginning of year	3,000	3,380	4,090	4,465	4,740
New deliveries	450	435	310	230	230
Less scrappings, conversions, etc.	(70)	(70)	(80)	(90)	(100)
Total, year end	3,380	3,745	4,320	4,605	4,870
Tonnage supply-demand balance:					
Average year availability	3,190	3,500	4,205	4,535	4,805
Estimated average year requirements	2,760	2,880	3,050	3,280	3,505
Theoretical surplus	430	680	1,155	1,255	1,300
Percent surplus	13	19	27	27	27

POTENTIAL DELIVERIES ASSUMED DURING CALENDAR YEAR

U.S. yards	60	45	30	30	30
Foreign yards	390	390	280	200	200
Total	450	435	310	230	230

STAFF NOTE.—Existing sources formed the majority of data utilized regarding coal. Extracts from major documents appear below.

Extract from "Toward a New Energy Pattern in Europe," OEEC, report of the Energy Advisory Commission, January 1960 (ch. II, pp. 15–19, pars. 8–17).

8. The importance of energy supplies and consumption in the economic development of Europe was emphasized by the Hartley Commission and we need not set out fully again the important part that it has played. Over the period since 1860 which is covered by reasonably trustworthy statistics there has been almost a thirty-fold increase in world production of commercial sources of primary energy, and this has been associated with and contributed to the great advance of industrial production and of standards of living that has occurred during this period.

9. In the following more detailed survey of recent trends of the production and consumption of energy in Europe we shall confine ourselves in general to the principal commercial sources of energy for which full statistical information is available[1]. We have attempted to make some allowance for the use for heating, lighting or power of wood, peat, wind-generated electricity and other non-commercial sources which are not wholly negligible in individual countries and regions.

10. In Table 1 we revise and bring up to date the statistics of actual consumption in the O.E.E.C. area[2] of the five primary sources of commercial energy—coal, lignite, natural gas, crude oil and hydro-power. To these a sixth, nuclear energy, must now be added. These, as we shall stress in our subsequent discussion, are in large part converted into secondary sources of energy in the course of consumption—electricity, manufactured gas, coke and petroleum products—but apart from

---

1. Our statistics of recent trends have mainly been taken from the O.E.E.C. Statistical Bulletin: "Basic Statistics of Energy for O.E.E.C. Countries, 1950-1958", published in October 1959.

2. Throughout this report, in conformity both with the normal practice of O.E.E.C. and with that of the Hartley Commission the O.E.E.C. area will be defined as the areas covered by the metropolitan territories of the Member countries of O.E.E.C. on the continent of Europe, together with the contiguous islands. Thus developments in French North Africa and any other possible developments within the dependent overseas territories and the currency areas of other Member countries lie outside the O.E.E.C. area as here defined. We shall take full account of these developments when we come to discuss in Chapter VII below the prospects and possible sources of imports of energy. In this report the O.E.E.C. area has sometimes been referred to as "Western Europe". The statistics were prepared before the admission of Spain to O.E.E.C.; figures for Spain are therefore excluded throughout.

the minor and unimportant sources mentioned in the last paragraph, all European energy consumption must derive ultimately from these primary sources.

TABLE I. CONSUMPTION OF PRIMARY ENERGY IN THE O.E.E.C. AREA[1]

YEAR	COAL *Million tons*	LIGNITE *Million tons*	NATURAL GAS[2] *1000 million cu.m*	OIL *Million tons*	NUCLEAR ENERGY *Net electricity production TWh*	HYDRO-POWER *Net electricity production TWh*	OTHER FORMS[3] *Million tons of coal equivalent*
1938	471.1	76.5		32.0	—	59.7	20.0
1948	420.7	78.8	0.5	40.4	—	85.4	20.0
1949	444.1	86.0	0.7	47.3	—	82.5	20.0
1950	447.4	90.0	1.1	55.9	—	99.0	20.0
1951	492.0	99.6	1.7	67.7	—	112.8	20.0
1952	485.1	100.2	2.3	72.1	—	119.7	20.0
1953	472.6	101.8	3.3	79.1	—	121.4	20.0
1954	485.3	109.6	4.2	92.6	—	132.5	20.0
1955	508.9	116.0	5.3	106.6	—	139.2	20.0
1956	520.8	120.4	6.5	122.4	0.1	146.7	20.0
1957	513.0	124.7	7.3	122.7	0.4	152.2	20.0
1958	473.3	124.4	7.7	142.4	0.3	172.8	20.0

1. Including bunkers for ocean-going vessels and taking account of the balance of foreign trade and stock changes in secondary forms of energy.
2. At 9 000 kcal/cu.m, including methane from collieries.
3. Such as fuelwood, peat, geothermal energy ; Secretariat estimates.

11. If we are to discuss the aggregate production and consumption of Western Europe as a whole and the contributions of the different

QUANTITY	ENERGY CONTENT 10^{12} *kcal*	COAL EQUIVALENT *Million tons*
1 million tons hard coal	7	1.00
1 million tons coke	6.7	0.96
1 million tons patent fuel	7	1.00
1 million tons lignite	2	0.29
1 million tons lignite briquettes	4.8	0.69
1 million tons liquid fuels	10	1.43
1 000 million cu. m natural gas	9	1.29
1 000 million cu. m manufactured gas	4.2	0.60
1 TWh hydro-electricity		0.40[1]
1 TWh nuclear electricity		0.40[1 2]

1. See Annex 1.
2. Corresponding to a plant efficiency of 2 800 kcal/kWh or 31 per cent. This rating has only been applied for 1975. See paragraph 117.

sources of energy, it is necessary to convert these various amounts of different sources of energy into a common unit. Our basic calculations have been made in kilocalories[1]. Following the precedent of the Hartley Commission, and because we think that for the layman it provides the most convenient concept, we have, however, expressed the main figures and tables in terms of tons of coal. The energy contents that we have used for this purpose are shown in the table above.

12. Table 2 shows the changes since 1948 in the consumption of primary energy in the O.E.E.C. area measured in millions of tons of coal equivalent.

TABLE 2. CONSUMPTION OF PRIMARY ENERGY IN THE O.E.E.C. AREA[1]

In million tons of coal equivalent.

YEAR	COAL	LIGNITE	NATURAL GAS	OIL	NUCLEAR ENERGY	HYDRO-POWER	OTHER[2] FORMS	TOTAL
1938	471.1	21.9	0.1	45.7	—	23.9	20.0	582.7
1948	420.7	22.5	0.7	57.7	—	34.2	20.0	555.8
1949	444.1	24.6	0.9	67.6	—	33.0	20.0	590.2
1950	447.4	25.7	1.4	79.9	—	39.6	20.0	614.0
1951	492.0	28.5	2.2	96.7	—	45.1	20.0	684.5
1952	485.1	28.6	2.9	103.0	—	47.9	20.0	687.5
1953	472.6	29.1	4.2	113.0	—	48.6	20.0	687.5
1954	485.3	31.3	5.4	132.3	—	53.0	20.0	727.3
1955	508.9	33.1	6.8	152.3	—	55.7	20.0	776.8
1956	520.8	34.4	8.3	174.9	.	58.7	20.0	817.1
1957	513.0	35.6	9.4	175.3	0.2	60.9	20.0	814.4
1958	473.3	35.5	10.0	203.4	0.1	69.1	20.0	811.4

1. Including bunkers for ocean-going vessels and taking account of the balance of foreign trade and stock changes in secondary forms of energy.
2. Such as fuelwood, peat, geothermal energy ; Secretariat estimates.

13. Certain very significant trends are immediately evident. The growth of the aggregate consumption of primary energy over the ten-year period has been very considerable: the consumption of 1958 was 46 per cent greater than that of 1948, equivalent to an annual growth of about 4 per cent. The rate of growth of consumption has been lower in the last few years than in the earlier years, when Western Europe was still in process of recovery from the effects of the War: from 1948 to 1955 the rate of growth of total energy consumption was close to 5 per cent. The growth of the contribution of hydro-power has been spectacular, the 1958 figure was more than twice that of 1948 corresponding to an annual growth of more than 7 per cent. The contribution of oil has increased almost four-fold.

1. See Annex 1.

14. Within this growing aggregate consumption, there have, as was pointed out by the Hartley Commission, been significant changes in the proportionate dependence on different sources of fuel. Coal, though it remains by far the largest source of energy, and though the actual amount of coal consumed had increased between 1948 and 1958 by about 13 per cent, is now proportionately a much smaller contributor than in the past. As may be seen in Table 3, the share of coal in the total has fallen from 81 per cent in 1938 and 76 per cent in 1948 to 58 per cent in 1958.

TABLE 3. CONTRIBUTION OF THE VARIOUS FORMS OF PRIMARY ENERGY TO THE TOTAL CONSUMPTION OF PRIMARY ENERGY IN THE O.E.E.C. AREA

Percentages.

YEAR	COAL	LIGNITE	NATURAL GAS	OIL	NUCLEAR ENERGY	HYDRO-POWER	OTHER FORMS	TOTAL
1938	81	4	.	8	—	4	3	100
1948	76	4	.	10	—	6	4	100
1949	75	4	.	12	—	6	3	100
1950	73	4	.	13	—	7	3	100
1951	72	4	.	14	—	7	3	100
1952	71	4	.	15	—	7	3	100
1953	69	4	1	16	—	7	3	100
1954	67	4	1	18	—	7	3	100
1955	65	4	1	20	—	7	3	100
1956	64	4	1	21	.	7	3	100
1957	63	4	1	22	.	7	3	100
1958	58	4	1	25	.	9	3	100

15. The increase between 1948 and 1956 (the highest point before the recent recession) in the consumption of primary sources of fuels was about 260 million tons of coal equivalent, or about 47 per cent. About 100 million of this was met by an increased consumption of coal itself. Another 120 million came from increased oil consumption. About 20 million came from the added contributions of lignite and natural gas which, though representing in the latter case a great proportionate increase of output, have accounted for less than 10 per cent of the total increase.

16. Between 1956 and 1958 there was a decline of total consumption of about 6 million tons of coal equivalent. But the decline of coal consumption was about 48 million tons. All other forms of energy consumption remained constant or increased. The increase of oil consumption was nearly 30 million tons of coal equivalent.

17. Towards this increased aggregate consumption of primary energy, a declining proportion has come from within Europe itself. Table 4 shows, again in terms of coal, the indigenous production of primary energy and the increasing gap between indigenous production and total consumption that has been met by net imports. In 1948-1950 Western Europe was importing less than one-seventh of its primary fuel requirements; in 1956 and subsequent years the proportion had risen to more than one-fourth.

TABLE 4. INDIGENOUS PRODUCTION OF PRIMARY ENERGY AND IMPORTS OF FUEL IN THE O.E.E.C. AREA

In million tons of coal equivalent.

YEAR	INDIGENOUS PRODUCTION							NET IMPORTS	STOCK CHANGES[1]	TOTAL CONSUMPTION	NET IMPORTS AS % OF TOTAL CONSUMPTION
	COAL	LIGNITE	CRUDE OIL	NATURAL GAS	HYDRO-POWER	OTHER FORMS OF ENERGY	TOTAL				
1938.....	476.2	21.6	1.1	0.1	23.9	20.0	542.9	35.0	+ 4.8	582.7	6.0
1948.....	398.6	21.8	3.1	0.7	34.2	20.0	478.4	86.1	— 8.7	555.8	15.5
1949.....	432.2	23.9	3.9	0.9	33.0	20.0	513.9	82.3	— 6.0	590.2	13.9
1950.....	441.6	24.7	5.1	1.4	39.6	20.0	532.4	81.6	—	614.0	13.3
1951.....	463.5	27.5	6.7	2.2	45.2	20.0	565.1	125.6	— 6.2	684.5	18.3
1952.....	475.0	27.6	8.4	2.9	48.1	20.0	582.0	122.7	— 17.2	687.5	17.8
1953.....	471.1	27.8	9.7	4.2	48.9	20.0	581.7	116.2	— 10.4	687.5	16.9
1954.....	475.4	29.0	11.1	5.4	53.4	20.0	594.3	136.2	— 3.2	727.3	18.7
1955.....	477.4	30.0	13.1	6.8	56.0	20.0	603.3	176.6	— 3.1	776.8	22.7
1956.....	481.0	31.8	14.7	8.3	58.9	20.0	614.7	209.3	— 6.9	817.1	25.6
1957.....	481.7	32.7	17.1	9,4	61.0	20.0	621.9	224.0	— 31.5	814.4	27.5
1958.....	472.2	31.9	17.9	10.1	69.2	20.0	621.3	231.7	— 41.6	811.4	28.6

1. — = put to stocks.
+ = taken from stocks.

EXTRACT FROM ELECTRICITY COMMITTEE, 10TH ANNUAL REPORT TO OEEC, DECEMBER 1959 (PP. 15–19, PARS. 29–34).

Thermal Plant

29. From 32,800 megawatts in 1948, installed thermal capacity already amounted to 75,700 megawatts in 1958, and is expected to be more than 106,000 megawatts in 1964. The average yearly rate of increase, after being 8.7 percent over the last 10 years, will work out at 5.2 percent for the 6 years for which forecasts have been made.

30. During the early postwar years, electricity undertakings were obliged, in order to secure a rapid buildup of adequate production capacity, to design powerplants on well-tried lines, though they may not always give the best performance; thereafter, rapidly rising demand up to 1956 often forced producers to postpone the closing down of older plant so that the average increase in efficiency of the total thermal installations was not so great as might have been hoped. Now only high efficiency plant is being built, and much obsolete equipment has been withdrawn from service; as a result average efficiency was 25.7 percent in 1958 compared with 20.7 percent in 1950. Further advances can, however, be expected and it is estimated that a rate of about 29 percent should be feasible in Europe toward 1964 (cf. table 4). Average efficiency in U.S. thermal power stations in 1958 was almost 30 percent, but it should be borne in mind that the coal used in power stations in the United States has generally a higher calorific value than that used in Europe and so makes for higher efficiency.

Table 4.—*Consumption of fuel by all public utility power stations using coal, brown coal, and fuel oil*

Year	Energy (10^{12} kcal) [1] consumed	Power production (Twh)	Specific consumption (kcal per kwh sent out)	Thermal efficiency (percent)
1950	338.9	81.5	4,158	20.7
1958	610.4	182.7	3,341	25.7
1964 (estimate)	839.2	281.5	2,981	28.8

[1] For particulars of the tonnages consumed, see tables 5 of annex 5.

31. Such rapid progress has been possible primarily because production has been concentrated in very high capacity power stations. A survey made in the United States in 1956 of 44 recently commissioned power stations [1] shows that specific consumption can be cut from 2,900 local/kilowatt-hours for a station with a capacity between 75 and 100 megawatts to 2,500 local/kilowatt-hours for a station of over 500 megawatts. At the same time, the cost of investment per kilowatt installed can be reduced from $175 to $130. Similar facts have been noted in the United Kingdom; a modern power station with five units of 200 megawatts can show a thermal efficiency of 33.5 percent for a cost of £53 ($148) per kilowatt installed, whereas a power station with

[1] Tenth steam station cost survey, Electrical World, Oct. 7, 1957.

six 30-megawatt units would have a thermal efficiency of only 25.5 percent for a cost of £73 ($221) per kilowatt installed.[2]

These ultrahigh capacity power stations are justified only in areas where consumption is sufficiently dense, and where a high capacity interconnected network already exists; these two conditions are now fulfilled in many areas of Europe. Several units of 125 megawatts are already in service among the stations planned; some units of 250 megawatts and even of 500 megawatts are included in the plans now in hand.

Table 5, which is based on material collected by the committee for its annual survey on equipment, confirms these figures. Most of the units put into service in 1953 had a capacity of 40 to 100 megawatts but, in 1958, units of more than 100 megawatts began to predominate, and in 1962 nearly 75 percent of the new units will be even larger.

TABLE 5.—*Thermal capacity installed in 1953 and 1958 and planned for 1962*

Year of coming into service	Units less than 10 megawatts	Units between 10 and 39 megawatts	Units between 40 and 99 megawatts	Units of more than 100 megawatts	Total capacity
1953:					
Megawatts	213	1,374	2,374	410	4,371
Percent	4.9	31.4	54.3	9.4	100.0
1958:					
Megawatts	137	989	1,879	2,545	5,550
Percent	2.5	17.8	33.8	45.9	100.0
1962:[1]					
Megawatts	76	394	1,360	4,740	6,570
Percent	1.2	6.0	20.7	72.1	100.0

[1] Incomplete figures.

32. Another important development concerns the type of fuel which power stations are equipped to burn. Coal and brown coal were formerly almost the only fuels used, together with blast furnace gas for power stations in the vicinity of steelworks. Recently, however, fuel oil and natural gas have entered the field to the extent that, in 1958, they already supplied 10 and 0.5 percent, respectively, of thermal production.

This tendency will no doubt be continued over the next few years. As a safeguard against possible price fluctuations and to insure more certain supplies, undertakings are increasingly building dual-fired power stations using coal and fuel oil.

Brown coal, wherever it is available, remains a cheap fuel and one which is being developed as rapidly as possible.

At the moment, natural gas is plentiful only in Austria, northern Italy and southwestern France. A fuel with a very high calorific value, it is used to generate electricity only if more suitable thermal and chemical uses for it cannot be found in industry. It is not at all certain that natural gas, even when more plentiful supplies are available (e.g. from the Sahara), could become a basic fuel for power stations; it will probably be used mainly as a supplementary fuel at times when other users of gas are reducing their consumption and it can be bought more cheaply.

[2] D. P. Sayers, Proceedings of the I.E.E., title 106 (1959), No. 25, pp. 16 to 20.

33. The power stations under construction reflect this trend very clearly. For some 23,000 megawatts, representing the increase in power stations' capacity, from now until 1965, the main characteristics of about 80 percent are already known. Of this total, 57 percent are designed to burn only coal, 9 percent brown coal, and 1.4 percent blast furnace gas; power stations fired by fuel oil or natural gas alone account for only 7 percent and 1.9 percent, respectively. The remainder (23.7 percent) is made up by multiple-fired stations, most of which can burn either coal or fuel oil, but some of which can also burn gas; such stations will obviously be found mainly in areas where competition is likely to develop, e.g., Belgium, Denmark, France, Italy, and the Netherlands. The other countries, particularly Germany and the United Kingdom, are planning to construct mainly coal or brown coal stations, but the United Kingdom already has some dual-fired stations which make for a certain amount of flexibility in consumption (cf. table 6).

34. The combined effect of higher thermal efficiency and progressive substitution of fuel oil, gas and, in due course, nuclear energy for coal means that, whilst remaining the staple fuel for thermal production, the rate at which coal is consumed will grow far less rapidly than the output of the power stations. Forecasts made by countries for 1964 are given in paragraphs 44 et seq.

TABLE 6.—*Power stations under construction or planned, by type of fuel used—Situation at Jan. 1, 1959*

Country	Coal	Brown coal	Blast furnace gas	Natural gas	Fuel oil	Coal and fuel oil	Coal or fuel oil and gas	Total
Germany	2,969	1,382						4,351
Austria		300		60	121			481
Belgium	735					470	115	1,320
Denmark						548		548
Spain	310	60			248	122		740
France	1,266	110	305	375	250	250	1,125	3,681
Greece		195						195
Italy					137	665	490	1,292
Netherlands	310					990	250	1,550
Portugal	50							50
United Kingdom	7,335				840	300	65	8,240
Sweden								300
Total	12,975	2,047	305	435	1,596	3,345	2,045	22,748
Percent	57	9	1.4	1.9	7.0	14.7	3.0	100

Reference: Twelfth survey of electric power equipment.

EXTRACT FROM "REVISED PLAN FOR COAL, PROGRESS OF RECONSTRUCTION AND REVISED ESTIMATES OF DEMAND AND OUTPUT," UNITED KINGDOM NATIONAL COAL BOARD, OCTOBER 1959 (CH. I; CH. VI)

CHAPTER I. INTRODUCTION

The National Coal Board's plan for the reconstruction and development of the coal industry was published as "Plan for Coal" in October 1950. The following pages give a brief sketch of the progress made in carrying the plan into effect and outline the changes made necessary by revised estimates of demand.

"Plan for Coal" was a general guide to investment policy, not a blueprint. It was realized that it would need to be continually revised in the light of changing circumstances, and the results of the first major revision were given in "Investing in Coal" published in April 1956. The general reconstruction plans were broadly unchanged but a sharp rise in the general price level meant that much more money would be needed to carry the plan through. Estimates of the future demand for coal had increased; indeed the Ridley committee's report,[1] published in 1952, estimated that inland demand would rise to 230 million tons by 1962, and that the export demand would then be 25–35 million tons a year. "Investing in Coal" did not envisage that a demand of this size could be met; the planned production by 1965 was 230 million tons from deep mines and 10 million tons from opencast.

As recently as 3 years ago, it was the general view, here and in Europe, that there would be an ever-increasing demand for fuel and power and a continuing shortage of coal.[2] The countries of the European Coal and Steel Community entered into large forward contracts for American coal. In this country, the Government made arrangements for oil to be used in power stations in the place of up to 9 million tons of coal. Exports were cut and some coal was imported at high cost. To keep imports to the minimum, as much coal as possible was produced, and collieries which would otherwise have closed were kept going.

Toward the end of 1957, the picture began to change. A moderate depression in industry reduced the demand for coal. At the same time, increased efficiency in the use of coal continued to have its effect. Most important of all, there was an increase in the use of other sources of energy, mainly oil, at the expense of coal. The decline in the demand for coal has continued in 1958 and 1959 and all the coal-producing countries of Western Europe are faced with an actual or potential excess of capacity. In Britain, it is no longer necessary to plan to meet a continuous increase in demand. While a second revision of the plan has become imperative, the board do not envisage a severe contraction of the mining industry. They are planning to meet a demand which is about equal to present production. This output will be got at higher efficiency.

The progress of reconstruction has been generally in line with "Plan for Coal," though plans for development in the coalfields inevitably change as additional knowledge is gained about the coal reserves and alterations occur in market requirements. Frequently there is a choice between working reserves from one existing shaft or another, or between constructing a new colliery and reconstructing an old one. It is not always possible to foresee, in advance of detailed planning, which of several collieries in a coalfield will provide the most economic access to fresh reserves, and whether collieries should be combined or maintained as separate units.

"Plan for Coal" envisaged that over 250 major schemes of reconstruction and development would be put in hand in the period to 1965.

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[1] Report of the Committee on National Policy for the use of Fuel and Power Resources. Cmnd. 8647.

[2] Cf., "Europe's Growing Needs of Energy—How Can They Be Met?"—a report prepared by a group of experts, published by O.E.E.C. in May 1956.

By the present date, 70 schemes have been completed, and 168 are in progress. By 1965, 90 more will probably have been started. "Plan for Coal" also envisaged the construction of some 50 fairly small drift mines to provide immediate output. This part of the program has been substantially completed. By 1965, some of the 50 will already have been worked out, and only 40 or so will still be in production. The plan contemplated that a score of large new collieries would be constructed. One has been completed and is nearing full production; 13 are in process of construction, and coal is being won from some of them; 2 or 3 may be sunk in the years immediately after 1965.

A comparison between 1948 and 1958 of the results of the 70 collieries with completed schemes shows that annual output from these collieries has increased by 5¾ million tons or 20 percent. Moreover, they provide modern and efficient capacity which can be economically exploited for many years to come. Their working conditions are generally better than those of the older collieries and where the scheme has included a coal preparation plant (as many of them have), the coal sold from them can be prepared more exactly and consistently to meet consumers' requirements.

While the reconstruction schemes, together with the new collieries and drift mines, formed the most important part of the plan, a great deal of work had also to be done in mechanization, in providing more and better coal preparation plans, and in furnishing the industry with central workshops and stores. Concurrently with the plan for the collieries, the board's carbonization industry was undergoing reconstruction. At the instance of the government of the day, the board undertook to maintain their carbonization capacity at the 1948 level. Nearly all of the plants that vested in the board have been reconstructed or replaced by new ones.

Capital expenditure since the vesting date will amount to nearly £900 million by the end of the current year. The magnitude of the work is not easy to grasp even when measured in money. In physical terms, 500 miles of main tunnels have been driven and there are 500 miles more to drive, apart from secondary roadways. In comparison, there are 90 route miles of tunnel in the London underground system. By the end of 1958, 35 new shafts had been driven; their total depth is over 12 miles. There are 18 more shafts being sunk. The reconstruction of a pit usually entails the erection of surface buildings equal in size to substantial factories and the provision of extensive railway sidings. The new coal preparation plant at Manvers in Yorkshire, the largest such plant in Western Europe, handles nearly 3 million tons of coal a year drawn from four collieries and, with its associated sidings, covers an area of 112 acres. Over 20,000 houses for miners have been built by the board near the new and reconstructed pits—19,000 of them in the 3 years from 1952 to 1955. This is about the same number as all the dwellings in the new towns of Harlow and Crawley put up in the 11 years to the end of March 1958.

Chapter VI. Summary

The plan outlined in these pages is for the production of 200 to 215 million tons in 1965 at a productivity a shift of 30 to 31 hundredweight and with a labor force of 587,000 to 626,000. Nearly the whole output will then come from about 550 collieries, 200 less than

now. Only about 2 million tons will still be coming from opencast sites, and about the same amount from the licensed mines. In the intervening years it will be the board's policy to secure a reduction in undistributed stocks of coal.

On the basis of mid-1959 prices, capital expenditure in 1960–65 will amount to £511 million, of which £440 million will be spent on collieries and £71 million on ancillaries. On the basis of 1955 prices, capital expenditure in the 10 years 1956–65 will be £175 million less than the "Investing in Coal" estimate. Nevertheless, reconstruction will be carried forward in general conformity with the program outlined in "Plan for Coal" and by 1965, 80 percent of the output will be coming from reconstructions and new collieries. Most of the capital expenditure will be financed from internal resources and, if wages and prices remain steady, reductions in working costs should enable surpluses to be earned. Throughout the period, however, the governing factor will be the level of demand for coal and the extent to which the challenge from oil can be met. The increased efficiency of the industry and the measures already put in hand to maintain and enlarge the market for coal should insure that for many years to come it will continue to provide the country's main supplies of fuel.

The basic figures

SALABLE OUTPUT (MILLION TONS)

	Actual, 1947	Actual, 1955	Actual, 1958	Estimate, 1965
Deep-mined output (including licensed mines)	187	210	202	198–213
Opencast	10	11	14	2
Total	197	221	216	200–215

MANPOWER EXCLUDING OPENCAST AND LICENSED MINES (THOUSANDS)

Total	704	699	693	587–626

OUTPUT A MAN-SHIFT (HUNDREDWEIGHTS)

NCB mines	21.5	24.5	25.3	30–31

CAPITAL EXPENDITURE EXCLUDING LICENSED MINES (£ MILLION)

	Actual, 1947–59 [1]	Estimate, 1960–65
Collieries:		
Major schemes	339	267
Other expenditure	361	173
Total	700	440
Ancillary activities	186	71
Grand total	886	511

[1] Including an estimate for 1959.

STAFF NOTE.—Discussions with United Kingdom National Coal Board officials led to the following correspondence:

LETTER FROM REVIEW STAFF TO THE NATIONAL COAL BOARD

* * * * * * *

I find that we have returned from our visit in London with the impression gained in my meeting with you and Mr. Collins that the trend of the cost of coal in the United Kingdom is down, not up, and that this downward trend will probably continue for at least the next 3 years.

Would it be possible for you to restate what you told me in our meeting concerning the price trend of United Kingdom coal, so that we may be sure that we understand it correctly?

* * * * * * *

LETTER FROM NATIONAL COAL BOARD TO REVIEW STAFF

* * * * * * *

You are quite right. Mr. Collins and I told you that there has been a declining trend of coal production costs in the United Kingdom over the last 2 years, owing to sharp increases in productivity since March 1958. We expect this trend to continue.

Hence there is no reason why the relative price of coal—i.e., relative to other fuels or to the price level as a whole—should rise during the next few years, although of course there are factors outside our control that can upset any such prediction.

Yours sincerely,

E. F. SCHUMACHER,
Economic Adviser.

LETTER OF REQUEST TO ATOMIC ENERGY COMMISSION

This will confirm our discussion * * * concerning assistance from the Commission in connection with preparation of a "Survey of World Reserves of Uranium and Thorium." * * *

* * * * * * *

TRANSMITTAL LETTER FROM ATOMIC ENERGY COMMISSION

In your letter * * * you requested the preparation of a "Survey of World Resources of Uranium and Thorium" * * *.

Enclosed you will find reports on "Uranium and Thorium Resources of the United States and Allied and Neutral Countries" prepared by the Commission's Division of Raw Materials. * * *

* * * * * * *

URANIUM RESOURCES OF THE UNITED STATES AND
ALLIED AND NEUTRAL COUNTRIES

I. Purpose and scope.

To determine the availability of uranium over the next 15 and 40 years.

II. Problems of appraising resources.

III. Technology of production.

A. Present

B. Expectable within 15 years

C. Expectable within 40 years.

IV. Uranium concentrations in nature - tonnages and grades by geographic areas.

A. As found and known to date.

B. Discovery potential.

V. Reserves of recoverable uranium.

A. Under 1960 technology and current average price of approximately $10/lb. U_3O_8 in concentrates.

B. Under 1960 price, but improved technology.

1. Imminent or expectable over the next 15 years.

2. Expectable over the next 40 years.

C. Under varying prices.

1. At double 1960 price - $20/lb. U_3O_8 in concentrates.

2. At approximately four times 1960 price - $40/lb. U_3O_8 in concentrate

VI. Capacity to produce - present annual rate of production vs. capacity.

URANIUM RESOURCES OF THE UNITED STATES AND ALLIED AND NEUTRAL COUNTRIES

I. Purpose and scope.

To determine the availability of uranium over the next 15 and 40 years.

II. Problems of appraising resources.

The relative youth of the uranium mining industry and the fact that most exploration to date has been confined to previously known favorable areas and formations are the fundamental causes of difficulty in appraising long range resources. Reasonably precise information is available on the developed reserves in the U. S., classified as indicated and inferred reserves, and to a lesser extent on the developed and partially developed reserves of the major foreign producing countries where exploration and development were supported by our procurement contracts. These comprise the bulk of the known or explored reserves and are in process of exploitation (Table IV. A). Additional undiscovered resources (Discovery Potential - IV. B) can only be partially and/or tentatively evaluated as to extent, grade, and economics of exploitation based on generally favorable regional geology or unexplored surface indications.

III. Technology of production.

A. Present.

Uranium mining technology does not differ in any significant way from that of mining in general. A variety of methods and equipment used in the extraction of other minerals have been adopted by uranium miners and adapted to their needs. Uranium produced in South Africa is a by-product or co-product of gold mining, and consequently any improvement in South African gold mining technology will also benefit uranium production.

B. Expectable within 15 years.

and

C. Expectable within 40 years.

Specific significant advances in mining technology in either 15 or 40 years cannot be predicted. A gradual improvement in general mining methods and equipment, primarily the latter, can be assumed to continue, but cannot be assumed to reduce appreciably the cost of the finished uranium product. Although in the production of certain metals there has been a progressive reduction in the average grade of ores mined in the last sixty years, due in part to lower mining costs as a result of advances in mining technology, comparable developments cannot be anticipated for the uranium industry. The copper industry benefitted greatly in the past fifty years

by the development of block caving in underground mining; the development of improved methods and equipment leading to lower costs in open pit mining; and the use of froth flotation in beneficiation.

The uranium industry has already taken advantage of all the past improvements in mining technology that could be applied, and metallurgical processes fully comparable in recovery with that achieved in other industries have already been developed and are operating. Specific new developments of this nature cannot be predicted. The nature and size of known presently economic uranium deposits is such that the unit cost reductions possible with extremely large mine output as in the case of iron and copper mining cannot be achieved. The best that can be expected for uranium deposits of the type now being exploited is a slow improvement common to the mining industry as a whole due to refinements in methods and equipment rather than to any revolutionary change. On the other hand, technological improvements in mining, milling and recovery and utilization of by-products could reduce the estimated cost of recovering uranium from the presently known high cost resources - shale and phosphate rock (V. C. 2).

IV. Uranium concentrations in nature - tonnages and grades by geographic areas.

A. As found and known to date - in some cases only partially explored.

	Tons of U_3O_8	Grade of uranium-bearing material % U_3O_8	Tons of U_3O_8	Ave. grade of uranium-bearing material % U_3O_8
U. S.	240,000	0.28		
	5,000,000	0.006		
Sub-total (rounded)			5,000,000	0.006
Canada	400,000	0.10	400,000	0.10
United Kingdom and Western Europe	40,000	0.17		
	1,000,000	0.03		
Sub-total (rounded)			1,000,000	0.03
Latin America	3,000	0.30		
	90,000	0.05		
Sub-total (rounded)			90,000	0.05
Asia and Far East *			20,000	0.10
Africa	8,000	0.50		
	400,000	0.03		
	2,400,000	0.01		
Sub-total (rounded)			3,000,000	0.01
TOTAL (rounded)			10,000,000	0.008

*Including Australia and New Zealand.

B. Discovery potential.

In addition to the quantities of uranium listed as found and known to date under A. above, substantial quantities may reasonably be expected to be discovered on the basis of general geologic evidence.

United States

Tons of U_3O_8	Grade of uranium-bearing material % U_3O_8
400,000	0.25
5,000,000	0.004

The high grade figure is the estimated discovery potential in extensions of ore districts and in areas the geology of which is similar to that of known deposits, and in which the conditions are considered favorable for ore deposition. However, the projected discovery of 400,000 tons of U_3O_8 could require a more intensive and more costly exploration program involving greater risk factors than that of the past ten years, and the incentive of an assured market over a long period of time. The present over-supply of uranium which necessitated current restrictions on the procurement program has practically halted exploration activity in new areas and new environments. As a result, information is no longer being accumulated on the resources and distribution of uranium at the rapid rate of the past ten years.

The low grade figure refers principally to the Chattanooga shale and similar formations in other parts of the U. S. which have been sampled only sparsely.

Canada

Tons of U_3O_8	Grade of uranium-bearing material % U_3O_8
200,000	0.10

This figure refers only to the possible repetition of ore bodies similar to those now known in the Blind River and Bancroft areas. The total potential for Canada cannot be guessed at. Uranium occurrences are widely dispersed (generally near the margins of the Shield) ranging from Great Bear Lake, Lake Athabasca, Blind River, and Bancroft to Quebec. The possibilities of further important discoveries with aggressive exploration are good.

	Tons of U_3O_8	Grade of uranium-bearing material % U_3O_8
United Kingdom and Western Europe	100,000	0.10
(Greenland)	100,000	0.03
(Swedish shales)	1,000,000	0.02

Latin America

Small deposits of the Colorado Plateau type have been discovered in Mexico and Argentina. These are not considered a measure of the potentialities of the regions and they do not supply a sound basis for a large quantitative estimate. The sedimentary basins lying within the Brazilian Shield area are considered on purely geologic evidence to have good possibilities for significant discoveries.

Asia and Far East

There is no sound basis for making a quantitative estimate of the potentialities of this large and geologically diverse

region. The bulk of the known reserves are in Australia, but they are relatively small and do not provide a basis for a quantitative estimate even for that continent.

Africa

Here again, because of the vastness of the region and the diversity of the geology no quantitative estimate of undiscovered resources is attempted. Considering, however, the known deposits, their diverse nature and the favorable regional geology, the likelihood of eventual discovery of substantial additional reserves of all known economic categories is considered good.

V. Reserves of recoverable uranium.

A. Under 1960 technology and the average current price of approximately $10 per pound of U_3O_8.

Area	Tons of U_3O_8	Ave. grade of ore in % U_3O_8
U. S.	240,000	0.28
Canada	400,000 *	0.10
U.K. and Western Europe	40,000	0.17
Latin America	3,000	0.30
Asia and Far East	10,000	0.15
Africa	400,000 *	0.03
Total (rounded)	1,100,000	0.07

*Based on the official government figures without supporting detail and the assumption that the entire reported reserve is available at $10 or less per pound.

B. Under 1960 price, but improved technology.

1. Imminent or expectable over the next 15 years.

The effect of improved technology on reserves within 15 years is expected to be minor - less than 10 percent - because:

a. There is no sound basis for predicting any revolutionary advance in technology.

b. The best that can be expected is a gradual and probably small reduction in costs obtained by refinements of methods and equipment.

c. No large bodies of sub-marginal mineralization that would become ore with moderately reduced mining and concentration costs are known.

There are some resources such as certain uraniferous phosphate beds, and certain high vanadium-low uranium ores that might be exploited with expanded needs for vanadium or phosphate products. However, the increased quantity of U_3O_8 thus made available would add only slightly to the assumed increase mentioned above.

2. Expectable over the next 40 years.

a. At 1960 prices, improved mining and milling technology over the next 40 years are not expected to increase substantially reserves of the type currently exploited (Table V. A.).

b. Continued exploration, a better understanding of uranium geology, and improved exploration technology can be expected to increase reserves of the type currently exploited substantially, probably in excess of the "discovery potential" estimated (IV. B.) if an adequate market exists.

c. The development and refinement of processes making economically possible the extraction of U_3O_8 and the sale of co-products from some of the low grade reserves listed in Table IV. A. can be envisioned as probable within 40 years. This is most likely to occur with respect to U. S. and African phosphate rock (about 3,000,000 tons U_3O_8) the uranium production rate from which would be limited by the rate of exploitation of the material for phosphates. It cannot be assumed that these deposits would be exploited for the uranium content alone and the phosphate content wasted.

d. Availability of uranium in higher grade shales even with recovery of by-products is less likely at 1960 prices, although a possibility.

C. Known reserves of uranium recoverable with 1960 technology

1. At $20.00 per pound of U_3O_8 in concentrates.

	Tons of U_3O_8	Average grade of ore % U_3O_8
United States	240,000 *	0.28
Canada	400,000	0.10
United Kingdom and Western Europe	1,000,000	0.03
Latin America	90,000	0.05
Asia and Far East	20,000	0.10
Africa	400,000	0.03
Total (rounded)	2,000,000	0.04

*In addition, a significant but indeterminable proportion of the low grade reserves of Table IV. A. would be recoverable.

2. At $40.00 per pound of U_3O_8 in concentrates.

It is believed that a major part if not all of the 10,000,000 tons of U_3O_8 listed in Table IV. A. would be available at $40.00 a pound.

VI. Approximate current rate of production:

	Short tons U_3O_8
United States	18,000
Canada	16,000
United Kingdom and Western Europe	2,000
Latin America	Negligible
Asia and Far East	1,000
Africa	7,000
Total	44,000 *

*Present producing capacity probably at least 15% greater.

THORIUM RESOURCES OF THE UNITED STATES AND ALLIED AND NEUTRAL COUNTRIES

I. Purpose and scope.

To determine the current and future availability of thorium.

II. Problems of appraising resources.

III. Technology of production.

IV. Thorium concentrations in nature - tonnages and grades by geographic areas.

A. As found and known to date.

B. Discovery potential.

V. Reserves of recoverable thorium.

A. At $10 per pound or less and 1960 technology.

B. Under improved technology or higher prices.

VI. Capacity to produce.

THORIUM RESOURCES OF THE UNITED STATES AND ALLIED AND NEUTRAL COUNTRIES

I. Purpose and scope.

To determine the current and future availability of thorium.

II. Problems of appraising resources.

The difficulties of appraisal of thorium resources are accentuated by the lack of adequate incentives to encourage any widespread or thorough exploration. The largest potentials presently known are in placer deposits in various parts of the world and in the uranium ores of the Blind River area, Canada.

The placer and vein deposits in the United States are mainly uneconomic under present conditions. Full production from other deposits in the world that might be economic at a market price of about $5.00 per pound of contained ThO_2 in nitrate compounds would exceed present demand; only a very small part of the potential Blind River thorium production is now being recovered; operation of the major placer deposits in the world in view of the present limited thorium market would depend upon the marketing of several

co-products which are also in oversupply or more cheaply obtained elsewhere. Consequently, in the absence of any sizeable thorium mining industry and the exploration and development which would necessarily support such an industry, resources of thorium can be only tentatively evaluated.

III. Technology of production.

The situation with respect to advances in thorium mining technology is similar to that of uranium; no revolutionary advances can be predicted. With reference to concentration of ores and isolation of the metal or some purified compound, however, since there has been much smaller experience in this industry than in the case of uranium, there perhaps exists a greater possibility for the development of new processes with lower costs than attained at present.

IV. Thorium concentrations in nature - tonnages and grades by geographic areas.

A. As found and known to date.

In almost all cases individual deposits have been only partially explored and evaluated. The area estimates are tentative. Since the totals embrace deposits of several distinct kinds, the grades of which cover a very wide range, estimates of average grades are not listed.

	Recoverable at approximately $10.00 per lb. ThO_2 or less	Low Grade*	Total
U. S.	20,000		20,000
Canada	200,000**		200,000**
United Kingdom and Western Europe			negligible
Latin America	10,000	100,000	110,000
Asia and Far East	250,000		250,000
Africa	50,000	100,000	150,000
Totals (rounded)	500,000	200,000	700,000

*Availability dependent on the economics of recovering and marketing the co-products - principally niobium.

**Thorium occurs with uranium. Availability dependent upon uranium market.

B. Discovery potential.

Because thorium has had a limited market there has been no real incentive for exploration, and the estimates given in A. above are much less firm than in the case of uranium. For the same reason there is not a sound basis for estimates of discovery potential. In spite of the fact that thorium is estimated to be several times more abundant in the earth's crust than uranium, there is considerable geologic evidence to support the view that resources exploitable at current prices may be smaller than those of uranium. On the other hand, the discovery potential for low-grade deposits, particularly those from which thorium is a by-product of exploitation for other materials, is very likely extremely large.

Listed below are the only quantitative estimates offered. They are based on known areas of mineralization in the United States, Brazil and India; reports of additional low-grade occurrences in Brazil and East Africa similar to those listed in A. above, but which have not been properly evaluated; and possible additions to known reserves in Southeast Asia, Africa, and Madagascar. The estimates are, as indicated, incomplete.

	Recoverable at approximately $10.00 per pound or less	Low Grade*	Total
U. S.	30,000		30,000
Latin America	20,000	100,000	120,000
Asia and Far East	250,000		250,000
Africa	30,000	100,000	130,000
Totals (rounded)	300,000	200,000	500,000

*Of the same type as listed under A above.

V. Reserves of recoverable thorium.

A. At $10.00 per pound or less and 1960 technology:

U. S.	20,000
Canada	200,000
Latin America	10,000
Asia and Far East	250,000
Africa	50,000
Total (rounded)	500,000

B. Under improved technology or higher prices.

Inadequacy of information prevents a detailed analysis of availability of reserves at varying prices. However, advances in technology considered reasonably possible coupled with adequate demand and price for co-products and a moderately higher price for thorium could make available the entire 700,000 tons of known reserves listed in IV. A. above. Furthermore, the increased exploration and development resulting from a larger and rising demand for thorium would be expected to rapidly prove the discovery potential estimated in IV. B.

Finally, both igneous and sedimentary rocks, quantitatively unevaluated, but with higher than average thorium content, are known in several areas of the world from which at much higher prices, large amounts of thorium might be obtained.

VI. Capacity to produce.

United States thorium production in 1959 was approximately 550 tons of ThO_2. The major portion was derived from an unusual vein-type deposit of the mineral monazite in South Africa.

Canada recently began by-product production from Blind River uranium ore in one plant with a capacity of 120 to 150 tons ThO_2 per year.

France has treatment facilities for producing 300 to 400 tons of ThO_2 from Madagascar concentrates. India and Brazil have monazite treatment plants each of which in the past has produced about 150 tons of ThO_2 per year. One plant in the United Kingdom has a capacity of about 75 tons ThO_2 annually.

STAFF NOTE.—Information on U.S.S.R. uranium and thorium resources is contained in the following memorandum by the review staff.

Estimated Communist controlled uranium production and reserves, 1960 [1]

Country	Annual production (metric tons of uranium metal)	Reserves [2] (metric tons of uranium metal)
U.S.S.R.		80,000–270,000
East Germany		100,000
Czechoslovakia		25,000
Bulgaria		15,000
Rumania		15,000
Poland		1,000
Hungary		15,000
China		20,000–100,000
Total	10,000–20,000	100,000–370,000

[1] If thorium is produced, reserves may be on the order of 100,000 tons of ThO_2.
[2] Figures rounded.

A. U.S.S.R.

1. *The Nature of the Information the U.S.S.R. has Released on Uranium and Thorium Deposits.*—Information released by the U.S.S.R. falls into two categories: those scientific and technical articles published prior to World War II; and those released since the war. The first can be characterized by either their academic approach as related to uranium and thorium minerals or their casual references to these minerals within discussions of minerals then important economically such as many nonferrous sulphide ores of bismuth, lead, zinc, cobalt, nickel, etc. The post-World War II information on uranium deposits (there has been little published on thorium) is again academic stressing the minerals present, their origin, etc., but omitting everything on location, reserves, the grade of the ore, etc.

2. *The Fergana Valley.*—

(*a*) The prewar literature centered attention on several deposits in the Fergana Valley in Central Asia with the emphasis on possible radium production. One area known to have been mined was described in detail while several other sites held out possibilities of being developed. The known prewar uranium mining site was Tuya Muyum, at the southeast end of the valley (40 22N, 72 36E). The Soviets have said that the deposit is mined out and no longer contributes to their yearly uranium production.

(*b*) Mailiy Su (41 14N, 72 22E), Uigur Say (40 50N, 71 05E), and Taboshar (40 35N, 69 45E) in the Fergana Valley have also been mentioned in the prewar literature as possible radium producers. The Mailiy Su and Uigur Say deposits were described as similar to those then worked for radium and vanadium in the Colorado Plateau of the U.S. The Taboshar deposit was described as a vein-type deposit (somewhat similar to the Saxony, Germany vein deposits). All descriptions suggest that these deposits could have been mined for uranium since the war. The distribution of the deposits from the west to the east end of the Fergana Valley (about 200 miles) suggests that other mineable deposits, some mentioned very briefly in prewar

literature, are present, and that the Fergana Valley and its surrounding mountains make up an important uranium mining district.

(*c*) Nothing has appeared in postwar literature on the three deposits, or any uranium deposits in the Fergana Valley. Papers which have been published on uranium minerals or methods by which uranium deposits have been formed may refer to Fergana Valley deposits in part. There is no suggestion however, that any uranium mining is conducted in the valley in any literature or any Soviet announcements. Yearly production and reserves are, therefore, presented as pure speculation.

(*d*) If uranium is and has been mined from Fergana Valley deposits since the war, the geology suggests that production has been modest as related to such western deposits as the Blind River deposit in southern Ontario or the Ambrosia Lake deposit in New Mexico. The first is producing up to 10,000 tons of uranium a year and the second several thousand although production could be increased several times on the later deposit if this were necessary. If production of this magnitude is taking place, a reserve of 10,000–30,000 tons may be possible.

3. *The Kara Tau Mountains.*—Pre-World War II literature cites vanadium-uranium deposits in this mountain range. The most important type of deposit is apparently a very low grade uranium-vanadium bearing shale. While the Soviets may mine such a deposit, there is no evidence of such an operation. Again, however several postwar studies describe minerals and uranium mineralization processes that could relate to such deposits. Reserves of 500 to 2,000 tons of uranium is suggested.

4. *The Urals.*—The Urals are an important source of a variety of metals. Thorium-uranium bearing monazite placer deposits have been described in prewar literature. A post war publication suggests that a uranium deposit might be located in the Urals. The varied geology of the range could result in the formation of uranium deposits, but it appears probable that, if present, they would be small. Reserves could range from 100 to 4,000 tons.

5. *The Krivoy Rog Area (Ukraine).*—A Canadian geologist visited the Pervomaisk uranium mine in the Krivoy Rog district in 1958 and the Chairman of the U.S. Atomic Energy Commission visited it in 1959. The former published his estimate of the production from this mine in the June issue of the Northern Miner, 1958. Mr. McCone visited this and a second mine located 30 kilometers to the north of the Pervomaisk mine.

(*a*) The nature of the ore which occurs in lenslike and disseminated bodies suggests that the Soviets may have difficulty in determining the reserves. The concentration plant visited by the McCone party was new suggesting that reserves must be present to support operations for a number of years. Based on a 10-20 year operation, reserves may amount to 15,000 to 50,000 tons of uranium.

6. *Estonia.*—Shales occurring along the northern coast of Estonia are the same as those mined for uranium in Sweden. Prewar literature indicated that the uranium potential of the formation was good although the grade was very low. Reserves may be as high as 100,000 tons of uranium or more, but over 100,000 tons of the ore would have to be mined and processed a year to yield 10 tons of uranium. (The

average U.S. deposit would yield about 200 tons of uranium for the same amount of ore.)

7. *The remainder of the U.S.S.R.*—There are many other potential uranium producing areas in the U.S.S.R. In a country as geologically diverse as the Soviet Union, tens of other possible mining areas may be present. A few on which the Soviets have published prewar studies include:

(*a*) *The Kola Peninsula and Karelia.*—Numerous articles on thorium and uranium bearing igneous rocks have been published. Although generally too low-grade to be economically mined, byproduct production from other raw material enterprises might yield a few tons of thorium or uranium a year. In addition the geology near Lake Ladoga just north of Leningrad looks especially favorable for uranium mineralization. Reserves may run from 100 to 2,000 tons and possibly much more if the Lake Ladoga area should prove to have good deposits.

(*b*) *The Ukrainian Shield Area.*—The area around Zhitomir and Vinnitsa over to the Czechoslovakian and Hungarian borders has geology favorable for uranium mineralization. The area's potential may be as good as that of Karelia and the Kola Peninsula.

(*c*) *The Northern Caucasus—Caspian-Aral Sea Area.*—Lying between the Krivoy Rog and Fergana Valley uranium districts as it does, this great expanse of territory lies in a belt of the earth's crust that has undergone repeated cycles of deformations that could result in uraniferous mineralizations. Prewar literature cites radioactive waters in the Caucasus. The literature also cites the presence of radioactive minerals in rock outcrops in the desert areas south of the Aral Sea. The possibility that uranium deposits are present in the ore is good. The reserves might run from 1,000 to 10,000 tons of uranium.

(*d*) *The Lake Issyk-Kul' Area.*—There is little that has been published to indicate the Soviets are mining uranium in the area. Bordering on the Fergana Valley uraniferous province suggests, however, that fair deposits could be present. At least one postwar paper presented by the Soviets at Geneva in 1958 cites ground water studies in the area and the high degree of radioactivity in the waters. Reserves, as with the previous section, may run from 1,000 to 10,000 tons.

(*e*) *The Altai-Zapadnyy Sayan Mountain Area.*—Prewar literature indicates the presence of thorium-uranium-bearing monazite deposits in the placer and pegmatite deposits of this area. Uranium mineralization may also have occurred and has been mentioned in prewar literature in the Minusinsk area. The area looks geologically favorable for several modest deposits and reserves may be as above: 1,000 to 10,000 tons.

(*f*) *The Trans-Baikal Area.*—This is a vast area in which many monazite placer deposits have been described in the prewar literature. In addition, the Slyudyanka area at the south end of Lake Baikal is a district in which a uranium-bearing niobiumtantalum mineral called pyrochlore is mined. Uranium deposits of a minor nature may be scattered throughout the area with reserves running from 500 to 5,000 tons.

(*g*) *The Aldan Area.*—Geology somewhat similar to the Trans-Baikal area may result in deposits yielding similar production.

(*h*) *The Soviet Far East and Maritime Province.*—Extremely diverse geological conditions may result in minor uranium deposits at many scattered sites throughout this area. Altogether reserves may be 500 to 5,000 tons.

(*i*) *Jurassic age subbituminous coals.*—A Soviet geologist has published several postwar articles on uranium present in Jurassic-age subbituminous coals in the U.S.S.R. A great number of small coal basins similar to the one described in the literature are scattered across southern Siberia on to the far east. Because so many are similar to the one described as related to the possibility for uranium mineralization, considerable tonnages of uranium may be derived from this source. Reserves might be on the order of 5,000 to 40,000 tons of uranium.

(*j*) *Other areas.*—The northern portions of Siberia have districts wherein the geology appears favorable for uranium mineralization. While climate might limit operations in the area, it would not curtail them. Perhaps 500 to 5,000 tons of reserves are present.

(*k*) Other districts such as the Permian Basin just west of the Urals might contain workable deposits with similar tonnages and reserves.

B. SATELLITES AND CHINA

1. *East Germany.*—Uranium is mined in both the provinces of Saxony and Thuringia. The Saxony deposits have been mined since 1946 and mining is believed to be coming to an end sometime in the 1960's. The Thuringian deposits are quite extensive and it is believed that mining will be carried out there for the next twenty years. It is believed that East Germany is furnishing sufficient ores to the USSR from which the Soviets can derive several thousand tons of recoverable uranium metal per year.

(*a*) The Saxony area consists predominantly of crystalline and highly deformed rocks. Mineral deposits occur at numerous places throughout the entire district and have been worked for many centuries. The uranium deposits were formed during the Permian period of geologic time. The rocks in this region may therefore be divided into two types or groups; one group includes the Permian and older rocks which are the hosts for uranium deposits, the other group includes Mesozoic and later rocks which have only small concentrations of uranium. Uranium deposits in the Saxony area are in ore vein systems and are chiefly associated with silver, cobalt, nickel and copper bearing veins. Principal known occurrences are near granite intrusions. Uranium minerals occur in veins in the granite at few localities, but the principal deposits are in pre-CAMBRIAN age schists, phyllites, and metamorphosed sediments.

(*b*) The Thuringian area, which is completely different geologically from the Saxony region, consists of sandstones and limestones which have been deposited in a basin during CAMBRIAN times. The uranium deposits in Thuringia are quite extensive and are believed to be due to intrusions during Permian or later geologic time.

2. *Czechoslovakia.*—

(*a*) Czechoslovakia is believed to be producing sufficient ores from which the Soviets can derive several thousand tons of uranium per year. This production is expected to continue during the next few years.

(*b*) The uranium resources of Czechoslovakia have been exploited for over a century, particularly in the vicinity of Joachimsthal (Jachymov). Most of the Czechoslovakian uranium mining operations are carried out in the veins of the Erzgebirge which extend into East Germany. The center of this area in Czechoslovakia is Jachymov, an area which has been mined for silver since the 13th century. Most of the ore occurs in vein type bodies as well as veins and disseminations. Uranium is also found in the Bohemian Massif and in the Carpathian Mountains. In general, the Bohemian Massif consists of pre-Cambian methamorphic and igneous rocks which have been intruded by polymetallic uraniferous bearing veins. The Ezgebirge and the Sudeten mountains consist chiefly of early Paleozoic sediments which have been folded, methamorphosed, and cut by granitic plutons.

3. *Bulgaria.*—

(*a*) Bulgaria started uranium mining in 1945 but the discovery of new deposits have kept production at a relatively level rate. This production is expected to continue for the foreseeable future.

(*b*) Although the Bulgarian uranium deposits are distributed more or less throughout the country, the greatest concentration of uranium is found in the region of Bukhovo. The rocks in this area consist of gray-black argillites and gray-green mica shists of Silurian age, dark-red breccia and conglomerates of Triassic age, sandy shale and sandstone of Jurassic age, and reddish and blueish compact and marly limestone of Upper Cretaceous age. Pliocene sediments are exposed in places. The uranium deposits consist of torbernite, metatorbernite, and autumnite filling cracks in a much fractured Silurian shist. The exposed part of the deposit is the oxidized zone of a deposit that probably consisted of a pitchblende-bearing vein or impregnation.

4. *Rumania.*—Most of the Rumanian uranium deposits are found in the Transylvanian Mountains, located in the eastern-central part of the country, which consists of folded and partly methamorphosed Paleozoic sedimentary rocks, cut by many plutons and overlain locally by Tertiary volcanic rocks. The greatest concentration of metallic mineral deposits in Rumania is located in these mountains. These include epithermal gold-silver veins in the southeastern part, copper deposits in the south-central part, iron and base metal deposits mainly in the central parts, and aluminum deposits in and adjacent to the northwestern part.

5. *Poland.*—

(*a*) Polish reserves are believed to be small and mining may cease in the near future due to the low grade of the ore. No high-grade uranium deposits have been discovered in Poland to date.

(*b*) Small low-grade quantities of uranium are mined in the Polish occupied zone of Germany known as New Poland. Geologically the area consists of methamorphosed pre-Cambrian and Paleozoic sedimentary rocks, cut by granite plutons of Caledonian (Middle Paleozoic) and Hercinian (late Paleozoic) age. This area contains metallic deposits of a variety of types including uranium, and is considered to be part of a uranium province that includes the northwestern part of Czechoslovakia and much of Saxony in East Germany.

6. *Hungary.*—

(*a*) It is believed that Hungarian reserves may be quite extensive since mining started recently and the deposits are of sedimentary type.

(*b*) Hungary started uranium mining in 1955. Most deposits are located in the Paleozoic, Mesozoic, and Tertiary sedimentary rocks of the Pécs region which have been folded and slightly faulted. The uranium deposits are in light-reddish marine sandstones and are widely dispersed. The mountains are of low and hilly relief. Some of the deposits are quite similar to those found in the U.S. Colorado plateau.

7. *China.*—Relatively little is known of Chinese uranium mining activities which started chiefly during the past 5 years. The Japanese had been mining uranium during their occupation of China but most of this uranium came from vein and pegmatite deposits in Manchuria. The main Chinese mining effort is believed to be in the western provinces of China although promising deposits are located throughout that country. It is therefore difficult to estimate Chinese uranium reserves, which may be an extensive as those of the U.S.S.R.

[Extract From *New Sources of Energy and Economic Development*, United Nations, 1957]

PART I

Chapter 1

METHODS OF USING THE NEW SOURCES OF ENERGY

With the exception of the thermal energy of the seas, the non-conventional sources of energy considered in this report have long been employed in a limited way. Thus the adjective "new" applied to solar, wind, geothermic and tidal energy refers more to methods recently devised for their exploitation than to these sources of energy as such.

Two main causes are behind the present augmented interest in the possibilities of the non-conventional sources under review: (*a*) the increasing demand for energy in a world whose fossil fuel reserves are limited, and especially the requirements in under-developed areas remote from power networks and from fuel supplies; and (*b*) the promising results now being achieved in research and in the development of new materials to related utilization of the new sources.

The variety of purposes for which the new sources may find important applications will be reviewed later. The present chapter endeavours, by way of introduction, briefly to describe the methods of use which have been devised or are being devised in respect of these so-called new sources.

Solar Energy

Solar radiation has long been used to hasten plant growth in greenhouses and to evaporate water in salt works. Modern solar energy exploitation, still mainly in the research stage, varies from measurement of solar radiation to advanced experimentation in numerous countries, including among others, Australia, the Belgian Congo, Burma, Egypt, France, French West Africa, India, Israel, Italy, Japan, the Netherlands, the Union of South Africa, the Union of Soviet Socialist Republics, the United Kingdom and the United States of America.

Basic processes for converting solar radiation into useful energy may be divided into two general groups: those related to heat and those related to light.

Thermal processes are now being developed either for obtaining heat at various temperatures or for direct conversion of solar heat into electricity.

The range of temperatures achieved mainly depends on the degree of concentration of solar radiation obtained by the collectors used. Low temperatures (below 100°C.) are the easiest to achieve. For this, flat plate collectors are used. Black radiation-absorbing metals, for example, are placed in a transparent enclosure and are thereby made to heat water or some other medium utilized for transfer of usable heat. Low temperature processes have many applications, such as those for heating and distillation of water.

Lenses of reflecting mirrors are necessary to obtain temperatures beyond a few hundred degrees. As these lenses or mirrors capture only the direct radiation of the sun, they must be turned frequently to keep the sun focused. The heat captured and the temperature obtained depend upon the quality of the reflecting surface and the precise shaping of the parabolic collectors. Accordingly, a distinction will be made between medium temperature devices and high temperature furnaces. The heat in the former, below 1,000°C., may be directly utilized in low temperature furnaces and in cookers, or may be transferred through media similar to those utilized with flat plate collectors to run engines of various types. High temperature furnaces (1,000°-3,500°C.) are used for industrial and research purposes to treat refractory or metallic materials, for chemical reactions and even to produce high pressure steam.

Solar heat may also be utilized for the direct conversion of solar energy into electricity. The process is based on thermocouples of two unlike metals joined as in a hoop. When one joint is placed in the sun and the other kept cool, an electric current is produced. There are, however, many difficulties in the exploitation of this process, and the over-all efficiency is low.

Solar radiation coming as light may be converted to useful forms of energy through various photochemical and photoelectric processes.

The basic idea in a photochemical process is simple. Certain chemical reactions produced by sunlight are known in which the reactants themselves, or photocatalysts mixed with them, absorb solar energy. Such photochemical reactions are interesting, however, only if the energy absorbed can be recovered in sufficient quantity in a reverse reaction under controlled conditions. The difficulty lies in finding controllable and practical reactions which, while offering the possibility of energy storage, deliver useful heat or, even better, produce an electric current.

Among photochemical processes, photosynthesis is the most important. Work on it is concerned not so much with the efficiency of chemical conversion as efficiency in utilizing and storing the maximum amount of solar energy through plant life; this involves a proper selection of plants and of the conditions for their growth. Interest is particularly centred on single-celled algae, notably *chlorella pyrenoidosa*, which can grow and multiply suspended in water and thus do not need soil.

Photoelectric conversions appear more promising. This is particularly true for physical photo-voltaic cells, widely utilized in photographic exposure meters. An

electric current is produced when solar radiation strikes a light-sensitive material, such as the long-known selenium, in a barrier-layer photo-voltaic cell. Modern cells, developed as a result of research in semi-conductors, are based on silicon and popularly referred to as solar batteries. Minute amounts of arsenic are melted with silicon of high purity to give negative-type silicon cut into thin wafers about the size of razor blades. The wafer then is coated with boron to produce a thin top layer of positive-type silicon. An electric field is set up because silicon has a valence of four, arsenic five and boron three. Light strikes down to the junction of the layers, the barrier-layer (or so-called *p-n* junction), and is able to separate negative electrons from positive charges. All the visible light and the short infra-red have enough energy to effect this separation, and when wires are connected to the *p* layer and the *n* layer, an electrical current of low voltage is sent through the wire.

Wind Energy

Wind energy has long been used for mechanical water pumping. However, modern utilization is aimed more towards electricity production, and studies in this field range from wind surveys to advanced plant design and testing. Electric windmills are in commercial production or actual operation in several countries, including Australia, Canada, Denmark, France, Germany, the Union of South Africa, the Soviet Union, the United Kingdom and the United States.

The kinetic energy in a colum of moving air or wind, which increases in cubic proportion to the velocity of the wind, is intercepted by a rotor or propeller, transforming the energy into usable mechanical power. The basic elements determining the energy obtainable are the speed of the wind, the size of the area swept by the rotor, and the conversion efficiency of the plant.

Whatever the diameter of the rotor chosen, electric windmills are designed to give their maximum power capacity at a chosen or "rated" wind speed. Energy in a wind of velocity beyond the rated speed is wasted, and in the case of wind with lower velocity, the energy input and conversion efficiency of the plant decrease rapidly. Windmills may in theory extract perhaps close to 60 per cent of the power in the wind, but in practice losses in the rotor and in the gearing, and electrical losses, are likely to reduce the over-all efficiency to some 40 per cent or less.

Tidal Energy

Exploitation of tidal energy has recently been studied more or less extensively in several countries, notably Argentina, Canada, France, the Soviet Union, the United Kingdom, the United States and also Brazil, Germany, the Netherlands, New Zealand and Spain. After intensive research and outstanding new technical contributions, France is going ahead with the first tidal project, La Rance, to be built in stages from 1957 to the winter of 1966, when the last units in the 342,000-kilowatt plant are expected to be put into service.

The mechanical energy of tides may be harnessed and converted into electricity. In principle, the conversion process is akin to conventional hydro-power, utilizing falling water. A basin is filled during flow tide and closed when the tide recedes, so that a difference in head on ebb tide is created, or vice versa. When the water is allowed to fall toward the lower side of the barrage, which contains sluices and machinery, it operates a turbine. The turbine in turn drives a generator producing electricity.

New ideas and refinements are arousing more interest in the possibility of utilizing tidal energy effectively. Instead of a single basin, two or more communicating basins may be built and utilized to give greater flexibility so that one basin generates power during the filling stage and another during the emptying stage, and water can be turbined between basins. More important, however, is the recent development of turbines able to operate in both directions of water flow and also to act as pumps, and a combination of turbine and electric generator in bulb-type units operating efficiently submerged in water.

Geothermic Energy

Practical utilization of geothermic energy for the generation of electricity is a fact in Italy, where facilities reached a capacity of 274,000 kilowatts by the end of 1954 and gave an annual output of nearly 2,000 million kilowatt-hours (462).[1] In Japan, work in this field includes a 30-kilowatt pilot plant tested in 1951, numerous test borings and plans for a 3,000-kilowatt station, while in New Zealand a 37,500-kilowatt plant reportedly is under construction. Other examples include a 275-kilowatt plant in the Belgian Congo in the Katanga mining area, two experimental units totalling 25,000 kilowatts authorized in Mexico, and designs for a plant in Chile with an initial capacity of 2,000 kilowatts and an ultimate capacity of possibly 60,000 kilowatts, using the Tatio geysers at Antofagasta, as well as plans for a 100,000-kilowatt plant on the California coast of the United States.

Large-scale use has been made of geothermic energy for heating in Iceland, where it is estimated that the steam fields could yield a total power of 300,000 kilowatts (463). The possibilities of heating with geothermic energy are also being explored in some other parts of the world, such as western United States and several regions of the Soviet Union.

Geothermic energy comes as natural steam or hot water, mixed with various chemicals, under pressure in hot springs and fumaroles. Provided the natural steam has sufficient volume, temperature and pressure, it may be led through a turbine driving an electric generator and then exhausted into air. In more advanced plants chemical by-products are also obtained.

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[1] Numbers within parentheses refer to items in the bibliography in part III.

Thermal Energy of the Seas

Contributions to the exploitation of thermal energy of the seas date back about thirty years to a demonstration in France of the possibility of producing energy from a small temperature difference between two masses of water and to experiments off Cuba a few years later. Intensified efforts in France, including full-scale testing of components, during the past fifteen years, are claimed to have solved the technological problems. Besides the French project at Abidjan, Ivory Coast, a pilot plant to produce fresh water in California may be mentioned.

The capture and conversion to useful energy of heat stored in sea-water represent an ingenious application of the principle that heat can be converted to mechanical work when two heat reservoirs of different temperature are available. Such reservoirs of enormous size are found in the sea, in which the surface water is heated by the sun, and in certain areas maintained at sufficiently higher temperatures than deeper water for the difference in temperature to be utilized.

The basic machinery comprises an evaporator, a turbine-generator set and a condenser.[1] The process operates as follows: the warm salt surface water enters a low-pressure vessel, in which a vacuum is created with an air gas extractor, and part of the warm water flashes into vapour. The steam thus produced is "inhaled" by a condenser cooled by cold water pumped up from a deeper layer. On its way, the steam is intercepted by, and drives, an extremely low-pressure turbine which in turn runs an electric generator. The condenser may be of the jet type, in which the steam mixes with the cold salt water, or it may be a surface condenser turning the steam into useful fresh water as a by-product.

The over-all conversion efficiency varies with the temperature difference. For electricity production, the temperature difference between surface and cold water must be about 20°C., which may require pumping from great depth, and tremendous quantities of sea-water must be used to produce a reasonable quantity of power.

[1] See figure 7 in part II.

Chapter 2

CHARACTERISTIC FEATURES OF THE NEW ENERGY SOURCES

Each energy source, conventional or non-conventional, presents a number of features which greatly affect its general economic value, the technology used for its exploitation and the variety of purposes it may serve. Most important among these features are the permanence of the sources, their reliability in respect of the energy supplies capable of being yielded, the conditions for utilization imposed by their location, the relative flexibility in size of the plants to exploit the energy, and the cost economics peculiar to these plants.

Health hazards and degree of simplicity of operation also are important features, but in this respect the utilization of the new sources, in contrast to some other sources of energy, presents no particular problem. Once installed, most of the plants are relatively simple to operate, and they do not create smoke, noxious by-products or problems of radiation.

Permanence of Sources

Except for geothermic energy, which may present characteristics of exhaustibility comparable to those of conventional sources of thermal energy, the new sources under review are inexhaustible and comparable in this respect with conventional hydro-power. Moreover, the new sources have little or no use besides energy application, and their utilization may also be advantageous from the point of view of conserving exhaustible resources for other uses, as in the production of chemicals, or for energy uses not easily adaptable to other sources.

Reliability and Continuity of Energy Supply

Geothermic energy offers firm or continuous supply and its utilization may be limited only by fluctuations in demand. The same applies to thermal energy of the seas, provided that the difference in temperature between cold and warm water remains fairly stable.

Solar energy, wind energy and tidal energy offer only an intermittent supply and raise the problem of storage or combination with other energy sources if uninterrupted demand must be met or if demand cannot be adjusted in point of time to supply. Solar energy is available only during daylight hours. Utilization is further limited by clouds and rain, which are not predictable, although non-focusing collectors can operate on bright cloudy days. Thus, solar energy is obtainable only during some 2,000 to 4,000 hours annually, or less than half the time. However, for certain purposes, particularly in non-power applications, such as some agricultural operations and water distillation, intermittence does not matter much; and for cooling and irrigation no problem arises since energy production and consumption coincide in time.

Wind power availability is never completely predictable. Even the windiest spots have calm spells. But variation in a given place from year to year or even between shorter periods is usually small. Wind energy is not limited to daylight hours and may yield more energy hours per year than solar energy.

Tidal energy is also discontinuous, but in contrast to solar and wind energy there is a regular periodicity in supply, the periodicity differing with location. Tides occur once in about twenty-four hours in certain parts of Asia and twice in a little more than twenty-four hours for the most part along the coasts of the Atlantic Ocean. Although occurrence and height of tides vary from day to day with the position of the moon, tidal energy is predictable and is not seasonal or dependent on precipitation.

The operating time of tidal plants can be increased and regulated by the use of reversible turbines, which allow operation both with incoming and outgoing tides, and by the use of pumps, which make storage of energy possible. Also, plants with multiple basins may provide power continuously. Of course these refinements increase total costs and perhaps even cost per unit of output despite longer operating hours. The Rance project, for example, which has a gross capacity of 342,000 kilowatts, is expected to have an annual output of 820 million kilowatt-hours or an average of 2,398 operating hours annually.

Whereas the problem of storing energy may be solved with relative ease in the case of tidal power, it is more difficult to solve with wind and solar energy. Where the energy is converted into electric power, the latter may be fed into a grid system as has sometimes been successfully tried with wind power. Otherwise, storage batteries must be utilized.

The storage of energy from an intermittent source is always expensive. One solution, however, is the development of random uses, that is, application on an interruptible basis, as in pumping water for domestic use or irrigation, drying fodder or other crops, grinding corn and other agricultural uses.

Heat storage of solar energy for use at night or on rainy days can be accomplished by the use of certain liquid or solid materials. Research is now going on in order to find a chemical which will absorb heat and release it when required and do so at low cost and with high efficiency. Whether or not storage devices are

likely to be developed cheaply enough for general use cannot, at this stage, be predicted.

Localization

With regard to the locational implications of the new sources of energy, a comparison with hydro-power can again be made. Geothermic and tidal energy, like hydro-power, can only be exploited in places determined strictly by geologic and geographic conditions. Geothermic fields are usually found in volcanic areas although they are known to exist in several non-volcanic formations and may be more numerous than is generally realized. Tidal energy exploitation not only requires a minimum difference of height between high and low tides but also a coastline with bays and estuaries permitting the construction of dams and storage basins.

Solar energy and thermal energy of the seas present more locational flexibility. Their use is nevertheless restricted to certain climatic zones or belts. While solar energy is available everywhere in varying degrees, its optimum utilization is limited to areas located between 40° north latitude and 40° south. The most suitable regions are the trade wind deserts owing to the low moisture in these areas over the year and the high solar radiation intensity.

Utilization of thermal energy of the seas is subject to similar limitations and in addition is restricted to coastal stations or floating stations. Present technology requires a temperature difference of 20°C. between surface water and deep water, a fact which limits location of plants — taking into consideration natural conditions alone — to a zone bordered by surface isotherms of +25°C. This is approximately the tropical ocean belt. In addition, the process might be utilized in polar regions, by use of deep water as a heat source and winter air as a cold source, or elsewhere on the basis of an auxiliary heat source. For practical utilization it is important that cool water be not too far off the coast nor too deep.

Wind energy is available in many more places than geothermic and tidal energy. The suitability of a location depends on mean annual wind speed and on the distribution of given wind velocities over the year. The best locations are along sea coasts, but there are great local differences, depending on geographic conditions and altitude.

Size of the Plant

In speaking of the size of plants suitable for the exploitation of new sources of energy, a clear distinction must be made between those employing solar and wind energy and those designed to use geothermic energy, tidal energy and thermal energy of the seas. Solar and wind plants are very flexible in a small range of capacity, down to a fraction of one kilowatt, and therefore are particularly suited for isolated farms or small communities. Wind units may range in size up to a few thousand kilowatts. Economy of size is difficult to determine because capacity is related to wind conditions at the selected site and upon the rated speed chosen, but in general the unit cost decreases with increasing size. Under certain conditions, however, several small wind power plants may be more economical than one large unit.

Solar energy capacity usually increases in direct proportion to size of collectors. In other words, there is little economy of scale. Furthermore, as relatively large-scale plants may be subject to wind hazards, it is generally considered more practical to have several small solar units than a large one. If such groups of solar plants can be combined as to maintenance, some economies in operation may be obtained.

Units for the other three energy sources in principle can be built in small size, but in practice the minimum size is over 1,000 kilowatts for plants using thermal energy of the seas (3,500 kilowatts net under the conditions at Abidjan), and generally also for geothermic plants beyond the pilot stage (3,000 kilowatts being the smallest size in Italy) and for tidal plants.

The scale of plant in the case of tidal geothermic energy is limited by energy resource conditions, purpose of plant and market. Tidal plants may be very large and employ many generating units; the size of the latter is limited, perhaps up to 25,000 kilowatts, and partly depends on the height of the tide difference. The main economy of scale in tidal plants lies in dam construction and other ancillary engineering works.

The size of geothermic plants depends primarily on local natural steam conditions. Although simple plants of small size can be built at quite low cost, the cost of drilling for and developing steam is a major factor. More refined units with larger turbines and generators (up to 25,000 kilowatts in the case of Larderello) permit a greater power output from a given quantity of steam; investment is higher in such steam-using plants but the unit cost decreases with an increase in size and a higher investment may be justified when demand is large, the steam supply limited, and recovery of chemicals also is desired. Steam exploration and development costs obviously are lower per kilowatt in larger plants.

For plants designed to utilize the thermal energy of the seas, a very wide range of plant capacity is feasible. Although no plant utilizing thermal energy of the seas is yet actually operating, it is believed that costs would rapidly decline with an increase in scale.

Pre-eminence of fixed costs

As utilization of the new sources of energy involves no fuel costs, fixed costs are of overriding importance. Once the plant has been constructed, the costs arising from plant operation are minor and as a consequence annual costs, as in the case of hydro-power, consist mainly of amortization and especially interest on capital.

Chapter 3

NEW SOURCES OF ENERGY AND ELECTRIC POWER SUPPLY

In assessing the value of new sources of energy for power generation, economic considerations applicable to industrial areas do not necessarily apply in underdeveloped areas. Social and economic gains to be derived in isolated communities, for example, may be so great as to offset costs which in a different situation would be considered unfavourable.

When the exploitation of one or more new sources of energy is contemplated, among the considerations which arise is the distance of the area in question from bulk supplies of electrical energy or fuel, the character and magnitude of the demand for power, and the expected cost of power from the new sources envisaged. But questions such as the reliability of power supply which may be required — or the non-reliability which could be tolerated — in the area concerned would have to be taken into account as well as the usefulness of energy from a new power source in combination with other local sources of energy. The final decision to be made would depend upon the purposes for which power is to be used and upon the abundance and cost of development of the complementary local energy sources.

The two preceding chapters have suggested the kind of possibilities as well as limitations the new sources of energy may present in the field of electricity. Except in the case of tidal and geothermic plants, the capacity of which would normally be associated with a large demand and an interconnected system, the role that most of the new sources may be called upon to play in this field is mainly of a local nature. It is likely to be not one of competition but of providing electricity where is is not available or at most of complementing a small local supply.

Among the characteristics which from an economic point of view differentiate new sources from conventional sources, the most important one may be the different degree of reliability in supply. For this reason, the cases where firm power can be expected from new sources are examined first. After that, the special problems arising where the supply is of an intermittent nature are reviewed.

Firm Power Supply

According to experience so far, only two of the new sources of energy can provide a firm power supply without the help of storage facilities: geothermic energy and thermal energy of the seas.

Geothermic Power Plants

Geothermic energy, under favourable conditions, can be used for the generation of low cost electricity. Among the natural conditions determining the economic usefulness of a geothermic field are the quantity, temperature and pressure of the steam, the size and life expectancy of the field. In addition to the natural conditions, the type of plant used and its degree of utilization are among the factors determining the cost of power from geothermic energy. If a sufficient market for electricity is available within transmission distance, large-scale production units are advisable because they reduce the specific steam consumption.

In the testing of new fields and in areas with a low electricity demand, small, simple units can be employed. Plants of this kind, such as those developed in Italy, for example, are compact and light single-block units, which are easy to transport and install. They operate on steam as it comes out of the ground and exhaust it into air; although they require much more steam per kilowatt-hour than more refined and larger units and do not provide chemical by-products, these units can operate smoothly and without frequent overhaul. One of the most desirable features of these small steam-using plants of simple construction is the low capital cost per kilowatt.

In the Larderello field in Italy, four major types of power plants have been developed, including the simple small-sized type described above. The three others are larger, have higher efficiency in steam utilization and involve recovery of chemicals from the steam. These four types, which are called cycles,[1] are described in Part II; their capital costs per kilowatt of installed capacity are as follows:

	Main generator unit (kilowatts)	*Net plant capacity*[a] *(kilowatts)*	*Costs (dollars per kilowatt)*		
			Power house	*Drilling and pipes*	*Total investment*[b]
Cycle 1 ...	3,500	3,500	43	135	178
Cycle 2 ...	12,500	25,000	142	90	232
Cycle 3 ...	25,000	100,000	102	65	167
Cycle 4 ...	12,500	25,000	138	65	203

[a] Not including auxiliary units, required for cycles 2, 3 and 4.
[b] In addition, 12 to 20 per cent should be added for studies, such as engineering studies.

It should be noted that the cost of drilling and of pipes cannot be precisely estimated as it depends largely on natural conditions such as depth of drilling, and hardness of rock. The figures given above are based on experience in the Larderello field only. Calculation of the average cost per kilowatt-hour is rendered

[1] Because various techniques are employed in cycling the steam, the "cycles" differ in use of heat exchangers, condensers, cooling towers and other equipment.

difficult by the fact that the amortization period is uncertain. Another complicating factor is the allocation of joint costs; in the above cases, costs attributable to recovery of chemicals appear to have been excluded, except for joint costs of drilling wells and of pipes. Assuming 7,500 hours of operation and an interest rate of 8 per cent, as is customary in Italy, and varying rates for amortization and operating and maintenance costs, one can estimate the cost per kilowatt-hour of electric power at 4 to 8 mills for cycles 1 and 2 and at 3 to 6 mills for cycles 3 and 4.[8]

If the chemicals in the natural steam have positive economic significance, recovery of them may lower net costs of electricity. The Larderello field, for example, was originally developed for the recovery of chemicals; the by-products recovered there include boric acid, ammonia, sulphur and derivatives such as borax, calcium borate, boron carbide and elementary boron, at unspecified costs and contribution to revenue.

Plants using Thermal Energy of the Seas

Although no plant using thermal energy of the seas is yet operating, the experience already gained at Abidjan on the Ivory Coast allows a number of interesting conclusions to be drawn. In the utilization of such energy, it is usually envisaged that plants would both generate electric power and produce fresh water. Also, the very large quantities of cold water pumped up from the ocean depths might be used for cooling purposes in hot climates after leaving the power plant. Considerable amounts of fish and plankton, useful for food, may be pumped up with the cold water; and, after part of the surface water has evaporated in the plant, the remainder may go for further solar distillation in subsidiary plants for capture of salt, magnesium and other chemicals concentrated in the sea-water.

Generally speaking, the cost of electric power would decrease with decreasing length of the cold water duct, with increasing temperature difference and with an increase in plant capacity. The Abidjan project is of small dimension; for power production alone, it would have a net capacity of 7,000 kilowatts and is estimated to cost $10 million. Adaptation for fresh water production may necessitate an extra investment of some $850,000, which could result in a fresh water output of nearly 15,000 cubic metres a day at an extra cost of 1.0 to 1.5 cents per cubic metre with an interest rate of from 4 to 7.5 per cent. Annual operation and maintenance costs for power alone are estimated at about 6 per cent of the initial investment. Interest and amortization may be estimated at about 60 per cent of total annual costs.

A maximum cost per kilowatt-hour of 18 French francs or about 50 mills is obtained as a first approximation with an interest rate of 7 to 8 per cent and a load factor of 8,000 hours.[9]

Under the conditions at Abidjan, it is estimated that an increase in size from 7,000 to 100,000 kilowatts might reduce the cost per kilowatt by two-thirds; an increase to one million kilowatts might lower the cost per kilowatt-hour to the order of one or two French francs or three to six mills, claimed to be competitive for electro-steel mills. More favourable sites than Abidjan may produce at a cost one-fourth lower if the length of the cold water duct can be reduced by two-thirds, and at half the cost if the temperature difference is 10°C. higher, as may be possible at Curaçao.

It would thus appear that on the basis of present knowledge, unless natural conditions or availability of industrial waste heat are unusually favourable, the economics of plants using the thermal energy of the seas would rarely warrant their establishment for power generation alone, the more so since potential markets would presumably be easily accessible from the sea for fuel carriers. When, however, local requirements for fresh water, and occasionally for other joint products or by-products, would be the main purpose, the cost of power may become comparable with that of other energy sources.

Intermittent Power Supply

Since the availability of tidal, solar and wind energy is intermittent, utilization of any one of these sources for electricity generation generally raises not only the problem of cost of production but also the special problem of coping with intermittence of output. Although the total annual production can be fairly well estimated, the output of power from wind and solar energy plants at a specific time is as unpredictable as the energy input. Supply of tidal energy and output of tidal power are predictable, and the latter can now be regulated.

The circumstances under which these new sources can become economic are closely associated with the possibility of utilizing effectively electricity produced on an intermittent basis. In so far as tidal power and possibly large-scale wind power projects are concerned, there is little doubt that their output normally will have to be fed into a grid system. For solar power

[8] In a long-term projection for Italy (460), a capital cost of $240 per kilowatt is used, and a cost of 4.7 mills per kilowatt-hour is estimated, compared with 9.3 mills for conventional thermal plants, 7.3 mills for run-of-river plants and 13.6 mills for hydroelectric plants with storage dams under conditions stated in this source. A tripling of geothermic power plant capacity and output in Italy by 1965 is foreseen.

[9] Another type of plant would involve an artificial island 100 kilometres off a South American port, with a net power capacity of 4,500 kilowatts and a fresh water output of 28,000 cubic metres a day; total costs are estimated at about $16.6 million and on the basis of expected contribution to revenue 74 per cent of costs are allocated to power production. A similar calculation concerns a floating station, which could be useful for support of shipping and other purposes, with net power capacity of 2,600 kilowatts and fresh water production of 14,000 cubic metres a day; total costs are estimated at about $10.6 million and 76 per cent of this similarly is allocated to power production. In both cases prices of 15 French francs or 48 mills per kilowatt-hour and of 20 francs or 5.7 cents per cubic metre are given, stated to be acceptable to the country in question in the first-mentioned case and found economical with an interest rate of about 4 per cent and a load factor of 8,000 hours.

plants and smaller wind power plants, however, the essential economic prerequisites are that the consumption point for electricity must be physically close to the point of production and that consumers can absorb intermittent power at the costs involved and are willing to do so.

Tidal Power Plants

Most tidal power projects under study at present — and the Rance project under construction — are of comparatively large-scale design, involving the production of hundreds of millions of kilowatt-hours in each case.

Until recently, lunar intermittence of tides has been regarded as a prohibitive obstacle to tidal power production. However, as a result of French studies and technological development of the reversible turbine, which can also act as a pump, the possibility now exists of adapting the intermittent output of a tidal plant, with a single basin, to the market demand of the grid system. This, of course, is possible only for part of the potential output, but the cycling of the various operations allows considerable flexibility. In the Rance project, for example, it is estimated that no less than 150,000 kilowatts of power can be guaranteed at peak load demand times.

Thus intermittent tidal plants may be effectively utilized within a grid system. Periods of low production or no production can be made to coincide with hours of low demand, the plants contributing capacity when it is most needed. In assessing the value of such tidal plants the value of the fuel which would otherwise be required for operation of high-cost producing plants is not the only factor to be considered; in addition, they reduce the need for and thus the investment in power plants otherwise necessary in the system. At favourable sites the investment per kilowatt of capacity in a tidal plant appears to be not higher — perhaps somewhat lower — than the average investment per kilowatt of capacity in hydroelectric power stations but because of sheer size large tidal plants may involve a total initial investment of considerable magnitude, and the low average number of kilowatt-hours per kilowatt must also be taken into account.

There are, however, not many sites which appear to possess all the necessary characteristics for an economic tidal plant. The most important factors are the amplitude of the tide, the surface area of the basin and the length of the dam required. The higher the tide, the larger the area of the basin available; and the smaller the dam required, the more favourable is the site.

The site chosen for the first tidal power plant, at La Rance in France, appears to be one of the most favourable tidal power sites in Europe though by no means the largest. The total investment cost is estimated, on the basis of 1954 prices, at about $91 million (32,000 million French francs, not including 800 million francs for research costs) and the annual electricity output at 820 million kilowatt-hours. With operating costs estimated at 1.4 per cent of investment, interest at 5 per cent and amortization at 3 per cent,[4] the production cost would average about 10 mills per kilowatt-hour.

Final determination of the economics of such a project will have to take into account also the length of transmission lines that are necessary, the present and future cost of electricity from alternative sources and the reliability of supply from such other stations. It is conceivable that successful operating experience with the Rance tidal power plant may lead to wider interest in tidal plants for countries with favourable sea sites and a suitable electricity system.

Small tidal plants, in a capacity range of 1,000 to 10,000 kilowatts, appear feasible for production of intermittent power provided a small basin is created and tides of sufficient amplitude are available. Although they would be of great interest for under-developed areas, such small plants are far from realization at present.

Solar Power Plants

Aside from the intermittence of sunshine, the chief obstacle to power generation is the low and variable energy intensity of solar radiation. Coupled with low conversion efficiency, this factor necessitates a large collection area. The output is closely related to the size of the area.

Utilization of solar energy for generation of electricity is, in principle, relatively simple, but with present technology and costs such power production is expensive,[5] irrespective of the process chosen.[6]

The simple flat plate collector, if it can produce steam at all, produces it at too low a temperature to be of economic use for electricity generation. However, recent improvements in collector design increase the feasibility of power production, and new materials may lower the costs of the collector; but the cost of the generating units for small capacity will remain high. It has been estimated that flat plate collectors and low temperature engines under favourable conditions could produce electricity at 50 to 60 mills per kilowatt-hour.

Concentrating collectors could produce high temperature steam, permitting higher conversion efficiency, but in this case the collector equipment is more complicated and costly. It appears too early to forecast the economic feasibility of generating electricity through this process. In any case, solar power generation may find only limited application and on a small scale;

[4] With an interest rate of 8 per cent and amortization of 2 per cent, the average cost rises to nearly 18 mills per kilowatt-hour.

[5] See, for example, estimates in bibliography references (29), (37) and (38).

[6] Low-voltage electricity converted directly from solar energy through silicon batteries, despite the long life of collection and conversion cells and the elimination of turbines and generators, appears economically prohibitive except for certain uses, such as telephones and radios in rural and isolated areas. The high cost of silicon cells, however, may be reduced drastically with a shift from present laboratory scale to mass production and with technological advances.

nevertheless, local application may be found useful in under-developed areas presently without electricity where relative cost may not be a primary consideration.

Wind Power Plants

The kilowatt capacity of a wind power plant is, it must be recalled, a function of rated wind speed, area swept by the rotor and over-all conversion efficiency of the plant. Since probably very little can be done with regard to conversion efficiency, rated speed and rotor diameter are decisive factors. The larger the rotor, the greater becomes the capacity, making for economy in size, despite the required increased height and sturdiness of tower. The cost per kilowatt installed for wind plants with some fixed value of rated wind speed thus declines with increase in size.[7] Although the wind plant can produce at relatively low wind velocities — production is possible down to half the rated speed — efficiency and output fall off rapidly. Wind power utilization and costs are thus affected by variability of wind velocity.

While an increase in rated wind speed sharply reduces the cost per kilowatt installed, it is not the only point to be considered. Account must also be taken of the number of kilowatt-hours to be produced per unit of capacity. The number of kilowatt-hours is also a function of the rated wind speed of the plant — decreasing with increase in rated speed — and of the annual mean wind speed at the site. Since the distribution around the mean (that is, the number of hours in the year with wind speeds of given velocity) has been found to be uniform in many areas, the annual mean wind speed is a good indicator of energy obtainable at the site. The higher the annual mean wind speed, the higher can be the rated speed of plant without serious loss of operating hours. The selection of the most windy location in the area is thus very important.

If a certain number of operating hours and a certain capacity are required in a given location, the choices available relate to the size of the rotor and to the use of a number of small units or one or more larger ones. In practice, a compromise has to be made between number of hours, rated wind speed and rotor (plant) size: manufacturers have to standardize units to a reasonable extent and, with the exception of a few medium-sized plants, only small units are on the market or in actual operation. Other medium-scale and large-scale (above 100 kilowatts) plants are experimental machines or prototypes under development.

When a windmill is operated in isolation to provide a small local supply, where there is no other source of power, a relatively low rated speed is likely to be chosen in order to increase the number of hours of operation at full capacity, even though this may result in some increase in the cost per kilowatt-hour. On the other hand, when the windmill is operated in combination with other power plants — such as medium-sized ones with Diesel plants or large ones in a grid system — a relatively higher rated wind speed is likely to be chosen, despite reduction of operating hours, if this reduces the cost per kilowatt-hour.

The cost per kilowatt-hour also depends on the rate of interest and, to a smaller extent, on amortization. For the main structure, or some 80 per cent of the investment, a depreciation period of twenty years appears reasonable, and ten years for the remainder, covering certain moving parts. Annual maintenance costs are minor.[8] As mentioned in part II, costs appear to range between 10 and 100 mills per kilowatt-hour for small electric wind plants with battery, between 6 and 60 mills for medium-sized ones (10 to 100 kilowatts) and 3 mills or more for large plants, provided that the electricity that could be produced annually is fully utilized despite the intermittent nature of the supply.

Combination of Energy Sources

Intermittent sources can provide electricity when their output coincides with the timing of demand; when demand cannot coincide in point of time with supply, a combination of energy sources is an alternative to energy storage in the utilization of solar, wind and certain tidal plants.

Since storage of electricity is expensive and certain electricity uses require precise timing, a combination of energy sources may be the only way to find a useful and economic place for the intermittent sources. In combination these sources can be economical, and thus in turn can make a useful contribution as long as another source is available to meet minimum firm power demand at any time.

On a small local scale, the problems of combination chiefly concern the intermittent wind and solar power, notably the question of how at least a minimum quantity of firm supply can be provided and how the non-firm or intermittent output can be usefully absorbed. In isolated places requiring only a very small firm supply of electricity — a few kilowatts — such as for lighting at night, there may be no choice but to use a storage battery, which can be replenished by solar or wind power. In villages or larger communities, however, the firm supply could be provided by steam engines using local vegetable waste or by small Diesel plants. As Diesel fuel is expensive and the supply of vegetable waste may be limited, such plants would operate only when no power was available from intermittent sources.

The combined use of one or more wind power and solar power plants together with one fuel-burning plant might allow a widespread use of electricity in small communities provided that the priority of loads is

[7] The cost varies with location but may be estimated at $420 to $560 per kilowatt for small electric plants, including battery, at $200 to $420 per kilowatt for medium-sized plants with a capacity of 10 to 100 kilowatts and at $140 to $280 per kilowatt for larger plants.

[8] With an interest rate of about 6 per cent and annual maintenance costs amounting to between 0.5 and 1.5 per cent of the initial capital cost, a range of fixed annual charges is suggested varying from 12 to 15 per cent for small wind plants, including battery, to 10 to 12 per cent for medium-sized ones, and 9 to 11 per cent for large wind plants.

carefully worked out and full use of random power is possible. In such a system a minimum (evening) supply is provided for and the possible maximum daytime output can be absorbed for rural industrial and handicraft purposes, for some agricultural applications or for fans and air-conditioning. Random or excess output can be used for pumping and similar purposes which require no time scheduling.

The combination of energy sources can be varied. Where, for instance, a small hydro-power station with a storage reservoir exists, larger wind power and solar power units could be employed for pumping water into the reservoir. When the reservoir has been filled the excess power of wind and solar power station could be used for purposes not requiring time scheduling. Such a combination might avoid the use of a Diesel or other fuel-burning engine but might require a somewhat larger market, such as several villages or a village and an industrial plant.

Where a grid system and a larger market exist, certain tidal plants, as noted earlier, may be operated to produce at peak load time and thus add to capacity, while still requiring combination in a grid system. Wind power plants can constitute only a limited part of the system capacity; nevertheless, there may be ample room for utilizing intermittent sources, particularly since the energy availability and contribution over a longer period can be accurately estimated.

Chapter 4

UTILIZATION OF NEW ENERGY SOURCES FOR APPLICATIONS OTHER THAN ELECTRIC POWER

The new sources of energy can be utilized in several applications other than generation of electric power. In fact, some of these sources, notably solar energy and thermal energy of the seas, may find more important utilization in non-power applications, some of which may acquire an economic significance equal to that of electricity.

The number of possible applications is especially large for solar energy. Several of these applications of solar and other new energy sources, however, are still in the research stage, and there are no definite indications whether they may become economic and useful, or when. This applies, for example, to the photolysis of water into hydrogen and oxygen. Other applications may yield results not directly related to energy supply. In the latter category should be mentioned especially utilization of photosynthesis in growth of *chlorella algae*, the dried powder from which may become valuable as food but on present indications (218) is far too expensive for fuel.

In this chapter a preliminary evaluation is made of some non-power applications, developed or in process of development, that may contribute to the solution or amelioration of important problems existing in many countries.

Production of Fresh Water

Fresh water is in short supply in many areas, and growing consumption of it all over the world is leading to rising water costs. Many countries, therefore, have research projects designed to find methods for the low-cost production of fresh water. Solar energy has a prominent place among the energy sources considered for such production, though the use of thermal energy of the seas may entail lower production costs.

Production of fresh water in solar stills is a simple process involving evaporation of sea-water or brackish water in flat plate collectors. Though solar stills appear to be economical in meeting small-scale demand in some parts of the world, solar-distilled water is at present too expensive for large-scale uses such as irrigation. Research now in progress is aimed at improving efficiency and at lowering initial investment and cost per unit of output.[1] No evaluation appears to be as yet available, however, on costs for stills employing selective radiation, or multiple-effect stills, two recent advances in solar technology.

A plant utilizing thermal energy of the seas may, as was indicated in the previous chapter, turn out considerable quantities of fresh water as a joint product with electricity. The cost of less than 1.5 cents per cubic metre estimated for the Abidjan project is exceedingly low, because this cost covers only the special additional equipment needed to produce fresh water, while in two other projects[2] water is calculated at nearly six cents; but in all these cases most of the costs are covered by the sale of electricity. Thus fresh water produced by this method would apparently be less costly than that produced by any other process known to be presently operating, provided that the jointly produced electricity has a favourable market. As electricity prices are often high in areas short of water, suitable economic conditions for such a combined plant may be relatively easy to find. Where the temperature difference between surface water and deep water is above 14°C. approximately, but insufficient for electricity production, that is, over a considerably larger climatic belt, this method could be used for the production of fresh water alone. However, no estimate appears to be available for the production cost of fresh water alone by this process. Moreover, outside power would be necessary for pumping of salt water and extraction of air.

Heating, Refrigeration and Air-conditioning

Energy requirements for space heating and water heating, refrigeration, air cooling and conditioning might be met, at least in part, by non-electric applications of solar energy and geothermic energy.

Geothermic energy can be used directly for house heating. An outstanding example is found in Iceland, where the homes of some 40,000 people or one-fourth of the population, as well as greenhouses and swimming pools, are heated by natural hot water pumped sixteen kilometres from the wells (463). Elsewhere, geothermic energy is exploited for heating only on a small scale so far, partly because natural steam or hot water can

[1] In the United States, for example, the research goal is to develop solar stills able to produce water for municipal supply systems at a cost of ten cents per cubic metre and for irrigation at three cents, or at prices lower than now prevail in some countries. It appears that present solar distillation costs are 80 cents per cubic metre of fresh water. It is estimated that a simplified design may bring the cost down to 44 cents and with improvements to 27 cents. On the basis of experiments it is hoped that the cost may be lowered to 22 cents and, with the substitution of plastics for glass, to 18 cents, the lowest estimate so far reported.

[2] See chapter 3, footnote 3.

be distributed only within a limited radius from the source.

The economic possibilities of using solar energy for house heating on a large scale, beyond what comes naturally through windows facing the sun, are limited by natural conditions. In the tropical zones where solar energy is most abundant, such heating is not required; in temperate zones least solar energy is available when it is most needed, and if solar radiation is to be the only heat source the collector has to be made large enough to provide for the coldest period. Moreover, some heat storage facilities are needed for nights and cloudy days. In spite of all these handicaps solar heating may prove useful in certain climatic areas in which the cost of wood or other sources of energy is high.

Water can be heated by simple solar collectors installed on the roof. Such solar water heaters are used in large numbers in several countries. The collectors vary greatly in type and price. In Japan, for example, very simple types cost about $20 and larger ones about $200. Costs of solar water heaters may be further reduced with improved methods and materials. At present installation costs are usually repaid by fuel savings within a few years.

Refrigeration with solar energy is still in an early stage of experimentation. Two different methods are possible. In the first, a solar engine may be operated, like any engine, to provide power for compressing and liquefying a gas as in the type of refrigerators now widely used. With this method the solar energy goes through several conversions and the intermittence of power supply is a disadvantage which is likely to limit the prospects of this form of solar refrigeration. The second and more unique method is based on absorption-desorption refrigeration;[9] a simple focusing collector is used for two or three hours for heat regeneration of certain chemicals, which may keep a box cold for twenty-four hours. Small, simple solar refrigeration units of this type, requiring certain manual operations, may become available at a cost of less than $50. Larger units would of course be more expensive but still advantageous, particularly because they could be used in the absence of a supply of kerosene, gas or electricity. More elaborate solar machines based on the same principle can produce ice.

Practical work on air cooling and conditioning with solar energy appears to have started only recently, and the operation of prototypes has not yet been reported. The temperature need not be lowered as much as in refrigeration, and discontinuous operation may be acceptable, so that energy storage is avoided. A solar cooling and heating system could be combined and thus make possible a longer, more economical operation. The air-conditioning equipment undoubtedly would be expensive, especially in terms of the financing problems usually encountered in under-developed areas, but its introduction would contribute greatly to work efficiency and comfort in hot climates.

[9] See figure 2 in part II.

Mechanical Power

Mechanical power may be produced and used, without conversion to and from electricity, for water lifting or pumping, grain milling and other agricultural and industrial work sometimes performed by animal and human labour. There is no need for generating equipment or electric motors, and operation and maintenance are simple. Mechanical power is obtainable from each of the five new sources of energy and could perhaps be used directly. Solar energy and wind power, however, are of chief practical interest, and small tidal mills may also be mentioned.

As mechanical power cannot, like electricity, be transmitted over distances, the point of production must coincide closely with the point of use, and the plant has to be relatively small. Solar engines can be moved to the point of use, whereas windmills are tied in location, such as at a water well, and unlike their electric counterparts are not multi-purpose machines. This locational inflexibility may raise costs considerably compared with those at more windy sites nearby. The supply of mechanical power from solar and wind plants necessarily is intermittent, but in many applications this handicap may be relatively unimportant.

The technology of mechanical windmills is well known. Such windmills have a long history and may still be found in large numbers, especially in connexion with water pumping, even where electricity has been introduced. The mills vary from simple designs, such as those made by local craftsmen at low cost in the Far East for operating water ladders in irrigation systems, to bigger, more efficient and costly machines used for pumping water from greater depth and for other work requiring considerable power. These mechanical applications can make a useful contribution, particularly in areas with high fuel costs or with no electricity; they may result in lower power costs and reduce other costs.

Solar engines operating on steam, hot air or gas are in process of development in several countries. An engine using sulphur dioxide and a flat plate collector is already on the market. Present cost data, in so far as available, indicate that a solar unit (solar collector and engine) requires an investment of several hundred dollars though the amount may eventually be reduced.

Furnaces

Solar furnaces operate at temperatures up to 3,550°C., considerably higher than those in conventional furnaces. They are already utilized in some industrial countries, mainly for testing materials, and may be applied on a semi-industrial scale for smelting minerals. By using no fuel or electricity the solar furnace largely avoids problems of impurities and allows refining or processing of high quality materials.

Solar furnaces larger than those used in testing devices are composed of many mirrors and various instruments focusing solar radiation on a container. The most famous solar furnace, constructed as a prototype at Mont-Louis in the Pyrenees, has a diameter

of 85 feet, contains 3,500 mirrors and has a capacity of 75 kilowatts. It permits fabrication of special steels, in batches of 100 to 120 kilogrammes at a time, as well as several other metals and refractory materials of appropriate value. Production of zirconium oxide, for example, is claimed to be sufficient to amortize the plant within 100 days of operation. This plant would be even more economical in areas with more favourable solar radiation. Another French solar furnace with a heat capacity of 1,000 kilowatts is planned, and operations on this scale apparently would be less costly than with other forms of energy (29). Though nothing appears to have been published on the economics of individual applications, enough is known to indicate that solar furnaces may become important for the small-scale refining of minerals and for certain chemical processes. The limitation to relatively small-scale output may be no serious handicap provided the product is sufficiently valuable or the location, such as in a remote mining area, favourable.

Cooking

Solar cookers represent the simplest form of application. Several types have been developed costing $15 or less, but none appears as yet to be cheap and convenient enough for mass application. While solar cookers have the disadvantage of being usable only when the sun shines and, in the case of the simplest cookers, only out of doors where the operator is subjected to the heat of the sun, their popularisation might be brought about through various forms of support. They could be used to advantage in villages, saving the work of fuel gathering, reducing the practice of burning cattle dung, which would be more valuable as a fertilizer, and averting other indiscriminate fuel collection injurious to the economy.

Miscellaneous Applications

Solar energy, in particular, has several other non-power applications such as those for agricultural heating and drying. Fruit and timber drying, for example, may be accelerated with flat plate collectors. Solar energy can also be trapped for frost protection at still undetermined costs by the use of plastic or other shields and by various methods of heat storage in the ground. Another use of solar energy is that for greenhouses, the costs of which may be reduced by the substitution of plastics for glass.

Solar evaporation of sea-water to produce salt is a simple operation which meets domestic salt needs in many countries and in some even makes possible substantial salt exports. Recent experiments show that addition of certain cheap chemical colourings to the salt water improves its ability to absorb solar energy and speeds up evaporation, resulting in more economic production.[4]

A unique potential future application worth mentioning, on which much work may be going on but about which little information is available, is in the field of astronautics or space travel. Solar power generation in this field has obvious advantages; for instance, the availability of solar energy is completely predictable, the radiation is more intense, and the transient energy source may eliminate the need to carry nuclear energy or other fuel.

[4] Such colouring may similarly be spread on snow to speed snow melting and thus to lengthen the growing season.

Chapter 5

CONCLUSIONS

As indicated in the preceding chapters, applications of the new sources of energy under review are, with a few exceptions, mainly in the applied research and prototype stage. In order to indicate what kind of action may be suggested in relation to their development, it seems appropriate, first, to consider the role which the new sources might be called upon to play in the context of present development of energy as a whole, and briefly to review the current work being done concerning them.

New Sources and Energy Problems

Recent years have witnessed an increasing awareness of the advantage which may be obtained in combining energy sources of various characteristics. One advantage, for example, is that such a combination may allow a country to economize on use of energy sources of a polyvalent nature, such as fossil fuels, which in some circumstances may be more important for purposes other than electricity generation.

In such circumstances, new sources of energy such as tidal, geothermic and to a certain extent, wind energy, may be called upon to play an important role where they are susceptible to large-scale exploitation for power generation. This, however, would mainly correspond to conditions existing in more economically advanced regions of the world.

There are other areas in the world where energy supplies — even of a random nature — are urgently needed for a variety of purposes and in small quantity. Some of these areas are too distant from bulk supplies of energy to make its import economical. This is the case of almost all under-developed areas where agriculture combined with some form of rural industry is the predominant means of supporting a population. Such areas cover large stretches of territory in various parts of the world, and many of them are within the limits of the zones where solar radiation is most concentrated and where favourable differences of temperature prevail at various levels in the sea. Others on the sea coasts may enjoy tidal conditions suitable for running small tidal mills adapted to power generation. In most of these areas spots could be found where wind speed averages would permit useful wind utilization.

Although not always identical, the purposes for which energy is needed in those areas are not so diverse that research and development efforts could not be easily concentrated on a few essential devices. Universally in these areas electric power would be most valuable. The same can be said for food preservation and the establishment of means of communication among isolated villages. Primitive means of water pumping is a major reason for lack of sufficient irrigation, while in large arid and semi-arid areas the lack of fresh water is the stumbling block in the way of any reasonable development in the foreseeable future.

Current Work concerning the New Sources

Some fundamental and applied research is being carried out in a more or less uncoördinated way by manufacturing firms, universities, research foundations, and philanthropic organizations. Numerous local and national organizations are specializing in one or more of the new sources of energy.

Specialized international meetings for presentation of technical papers have been held in recent years on such subjects as the energy of the seas (Paris, June 1956), solar and wind energy (New Delhi, 1954), solar energy (Tucson and Phoenix, Arizona, 1955), and solar furnaces (Phoenix, 1957). Papers have also been presented on each of the five new sources at one time or another at meetings of the World Power Conference. The United Nations Educational, Scientific and Cultural Organization has played a special role in encouraging solar and wind energy research, while the World Meteorological Organization has devoted some attention to study of wind conditions. The development of solar energy utilization may receive a great impetus from the recent establishment of an Association for Applied Solar Energy, the only international organization specifically devoted to any of the five new energy sources.

A certain amount of knowledge about suitable locations for new energy plants is already available either as a result of special studies on utilization of a specific energy source or as a by-product of other work such as the compilation of records of solar radiation and wind conditions for weather and general climatological studies. Little information exists concerning the areas where geothermic, tidal and thermal energy of the seas could be developed.

Suggested Priorities

From this brief review it appears that in order to develop the utilization of the new sources along the lines of the role they are most likely to play in the near future, some concentration of work on a few schemes would be advisable as well as a better coördination of efforts.

While research concerning large-scale projects useful for combining diverse sources of energy for the production of power in more developed areas is likely to attract the attention of the authorities concerned and their financial support, the case may not be so simple as regards the need for small devices adapted to the requirements of under-developed agricultural areas. There is a risk that such small devices may be neglected because they may not always appear to offer sufficient economic incentive.

From the point of view of helping under-developed areas the following fields of applied research appear most urgent: application of solar, wind, geothermic and tidal energy to power generation in small units; of solar energy to telecommunication devices, to small refrigerating units, to water pumping and to cookers; and of solar and thermal energy of the seas for the production of fresh water. None of these applications offer major problems from a technical point of view. Experimental devices already exist and what would be required is further applied research not only for the development of small devices and their simple handling but also the development of cheap materials in order to keep the cost of the devices as low as possible.

It would also be useful if a few experimental schemes under practical conditions could be carried out in various parts of the world. They might *inter alia* be directed towards development of the best techniques for combining local energy resources to meet the energy needs of individual communities.

Meanwhile, surveys should be organized, on a preliminary basis at least, in areas where one or several new sources might be used, and simple surveying methods should be devised for measuring and recording needed data.

In all these fields the development of new sources of energy needs encouragement and support. This will have to come mostly from the industrial countries, which, although they may stand to benefit only indirectly from the suggested schemes, are in a better position from the point of view of technology and financing ability.

Equally important, however, and eminently suitable for international action, are (*a*) a systematic exchange of information among the institutes and organizations concerned with the study and application of new sources; (*b*) co-ordination of efforts; (*c*) provision of technical assistance where it is needed; and (*d*) pursuit of economic studies in this field.

STAFF NOTE.—Due to the date of the foregoing United Nations publication, an effort was made to contact the authors, and to solicit updating of their studies. Resulting correspondence and papers appear below.

EXTRACT FROM COMMUNICATION

* * * * * * *

I read with great interest the United Nations publication "New Sources of Energy and Economic Development" and was particularly interested in your contribution to part II of that report. It would be of great assistance to me if you would send me a brief letter commenting upon any subsequent developments on the use of tidal energy which have taken place since the publication of the United Nations report. Such a brief commentary from you would be of great assistance in this review. It would be my hope that your communication could be published as an addendum to the original U.N. report, which we plan to reprint along with other pertinent material gathered in connection with the review.

* * * * * * *

ADDRESSEES

M. R. Gibrat, professor of industrial power, Ecole Nationale Superieure des Mines, Paris, France.
M. C. Beau, director general, Energie des Mers, Paris, France.
E. W. Golding, O.B.E., Electrical Research Association, London, England.
F. Daniels, chairman, Department of Chemistry, University of Wisconsin, Madison, Wis.
R. Allessandri, Direttore Dipartamentale, Ferrovie dello Stato, Bologna, Italy.

TEXT OF A LETTER FROM R. GIBRAT

I was very pleased to hear that my contribution to the publication by the United Nations on the "New Sources of Energy and Economic Development" had caught your attention.

According to your wish, you will find hereafter further information regarding the use of tidal energy.

With the exception of France, few developments have taken place since 1957. Let us yet point out a renewed interest in Russia, which has appeared particularly in visits of Soviet engineers in France, and more recently in a report which Bernstein wrote for the Literary Gazette of Moscow. In his report, Bernstein reviews different projects, for instance the Mezen project on the White Sea, and anticipates an extensive system of electrical interconnexions between France and U.S.R.R. which may seem rather premature.

On the other hand, in France, a first full-size tide-driven group (9 MW) was started up quite successfully in Saint-Malo (Brittany) on the 4th of November 1959, in a specially equipped sluice tide gate. It is a turbo-alternator bulb group with horizontal shaft allowing the ten following working positions:

1°: Direct working turbine. The sea is lower than the water level of the dam.

2°: Reversed turbine. The sea is higher than the dam water level.

3°: Direct pumping. Machines acting as pumps and the alternator acting as a synchronous motor pump water from the sea to raise the dam water level.

4°: Reversed pumping. Its definition is obvious.

5°, 6°, 7°, 8°: These four working states correspond to a given way of rotation, but groups can also run in the opposite direction owing to the new

shape of the specially designed turbine blades, allowing these four more working states.

9°, 10°: Direct and inversed sluice. When stopped, the groups let in or out large quantities of water in order to accelerate the passing from one working state to the other.

This prototype group has now been working for six months, showing an extreme flexibility, and allowing all transient stages in a very satisfactory manner. The efficiencies measured with utmost care have often generously come up to the hopes given by the studies on reduced-scale models, and the important point is that the full-size experiment confirmed our views on corrosion by sea water, so that we can be quite certain in choosing the metal of the turbine blades.

Therefore, the French Government is again deeply interested by this project, and the Prime Minister—Monsieur DEBRE—solemnly announced the Government's decision. This let us think that the construction of the Rance project will start this very year, just as it is determined today.

Its main characteristics are as follows:

24 groups, power 10 MVA each, cos φ=1 (upstream bulb)

outer diameter of wheels 5.35 m, four adjustable blades, speed 93.75 turns per minute

the dam will be designed so that eight additional groups can be installed later if necessary.

In the present state of the project:

installed power 240 MW, annual production 567.5 BWH

average Winter power (full hours) 96.8 MW

peak power 194.5 MW

The cost of the work, on the basis of economic conditions of May 1959, taking in account unforeseen expenses, is 395 Millions of new Francs (39.5 Billions of ancient Francs).

Such a scheme compares very favorably with the conventional sources of energy.

I hope you will find my answer satisfactory, and I remain at your disposal for any further information that you may require.

M. C. BEAU NOTE ON A BROADER PERSPECTIVE OPENED TO THE THERMAL ENERGY OF THE SEA BY RECENT SURFACE NUCLEAR EXPLOSION TESTS

In 1957 the United Nations published a study entitled "New Sources of Energy and Economic Development." On p. 121, under the heading "Superheating of the Heat Source," it is said: "A new general orientation, perhaps less clearly delineated, is towards increasing the yield by preliminary superheating of the heat source by means of solar, atomic, or geothermic energy. The amount of steam emitted is proportional to the difference in temperature between the hot and cold water, and for an equal amount of steam, the energy produced is also proportional to the temperature difference (as the height of the fall in the case of a waterfall). The power obtained is, therefore, proportional to the square of the temperature difference, whence the great interest in the possibility of gaining a few degrees by superheating of the heat source.

Since this indication of principle, underground tests in the United States, proposed tests along the same line announced in the press, as well as statements made to the O.N.U. by the French Government, show that the orientation cited above is passing from the thinking to the concrete stage.

As soon as the use of nuclear explosions was mentioned, the fear of radioactive fallout appeared. But, since the publication of the O.N.U.

study, new tests have tended to eliminate this fear and opened the door to a series of peaceful applications under reasonable conditions.

In this connection here are the words of Dr. Edward Teller, of the University of California, one of the world's most eminent physicists, who speaks from experience: "After explosions in the air Rainier has proven that nuclear energy can be used for useful purposes undreamed of until now."

Operation Rainier mentioned by Dr. Teller is the underground explosion of a small nuclear bomb, equivalent to 1,700 tons of TNT, in the Nevada desert in September 1957. He also states: "Most important, we have learned that massive rock formations can be dislodged without attending radioactive fallout. Practically all the radioactivity was concentrated in a 10 cm. thick lava bed produced in the excavation by the thermic effect."

Concerning the use of nuclear explosions for large surface works, he has this to say: "We have at our disposal today hydrogen bombs producing such a slight amount of fallout that, with complete safety, we will be able to cut navigable lanes in many areas of the globe, at a saving of 99% over the cost of classic explosives."

Finally he adds: "We hope this year to explode a nuclear bomb in a saline deposit at the bottom of a pit 365 meters deep (this has recently been announced in the American press). We believe we can contain the heat liberated by the explosion, bring it to the surface, and transform it into energy, as is done in Italy and New Zealand with heat from the volcanoes. If this project is economically feasible, it will be possible periodically to explode thermonuclear bombs below ground which will give us electricity at low cost."

American experience in this field is far advanced for we know of four underground tests that have been made.

In relation to foreseeable new applications, the use of the thermal energy of the sea and the parallel massive production of fresh water in desert areas as byproduct, it is fitting to acknowledge the contribution of an eminent French scientist, who foresaw the possibilities long before the Americans did. In an article in *Tropiques*, Mr. Camille Rougeron discussed the process by which the thermal energy of the sea could be combined with nuclear explosions and geothermic energy to irrigate desert coastal areas. His statements, based on sound reasoning, appeared at the time as a prophecy for a remote future.

His general idea was as follows (attached are schematic drawings taken from his article): A bomb is exploded at the sea shore so as to form, without surface projection, a crater of rock debris through which the water can penetrate into the explosion chamber. On the way it is heated gradually by the calories from the bomb and the natural calories from the depth of the earth. This heat can be communicated to the water because of the large contact surfaces produced by the dislocation of the rocks. The water can then be extracted (through a well or through a second atomic crater linked to the base of the first by a chamber produced by means of a third, smaller explosion) and used to feed a powerplant, the temperature of the water being maintained by geothermic energy.

It should also be noted, incidentally, that since hot water is lighter, it can be collected at a sufficiently high level to feed an hydraulic plant before it is used in the thermal plant.

Usually one thinks in terms of a 20° difference in temperature between surface and deep water. In order to feed normal marethermic plants and gain a few degrees, the water will have to be drawn from a depth of several hundred meters, which points out the economy of pipe lines for drawing the cold water. Since the power produced in sea powerplants is proportional to the square of the difference in temperature, it can be seen that the power can be increased 4 or 5 times at no extra cost if the difference in temperature is increased to 40° or 60°. Whence the great interest in the combining the thermal energy of the sea with nuclear explosions for useful purposes.

It should be noted also that two of the four tests that followed Rainier were devoted to the formation of craters of the type suggested by Camille Rougeron. In these cases, as in Rainier and other tests, the water extracted from the explosion chamber after contact with the rocks in the chamber was practically nonradioactive, although the bombs used were not thermonuclear and were several hundred times more radioactive than thermonuclear bombs in which the fuse only is radioactive.

This outline, based on well thought-out concepts as well as on practical experience, indicates that the many developments that can be foreseen in the not too distant future stem from the 1956 theories of Mr. Rougeron.

More specifically, in regard to the production of fresh water, let us remember that in the Abidjan and Guadeloupe projects, where the power was only 3,500 Kw., approximately 7,000 tons of fresh water were condensed per day. This large mass of water which can be collected in surface condensers (a case studied in detail for Guadeloupe) could very well be the key to the irrigation of deserts near the sea or even at some distance where the use of pipelines would permit the amortization of the high costs involved.

It should be noted also that this process for obtaining hot water could be used in nontropical and even polar regions. In the latter, the residual heat in the water, after its passage through the evaporator, could be used as another byproduct, very valuable in view of the local temperature.

This outline points out the interesting developments that can follow the path opened by the tests and studies made since 1957.

FIGURE 1

FIGURE 1.—Formation of a crater by an underground explosion. The explosion first opens up a spherical "compression chamber" at 0. The pressure inside the chamber then chisels the soil or rock along the curve AOB, and throws up fragments into the air. Some of these fall back into the crater while others fall outside and form the lip. Underground explosions are governed by a geometric law of similarity: the linear dimensions of the compression chambers and of the craters are proportional to the linear dimensions of the explosive charges, and are therefore proportional to the cube root of their power. This law is valid for atomic explosions up to a few kilotons.

FIGURE 2

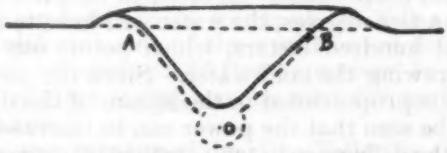

FIGURE 2.—Thermonuclear crater formation. For high power explosions, several megatons for example, the law of similarity applies also to the dimensions of the cones chiseled in the rock, whose volume will reach several billion cubic meters. But as a result of this law, proportionality of volume to power, the rocks dislodged will be thrown up to the same height only for a smaller crater; in a large crater they will practically all fall back, inside.

FIGURE 3

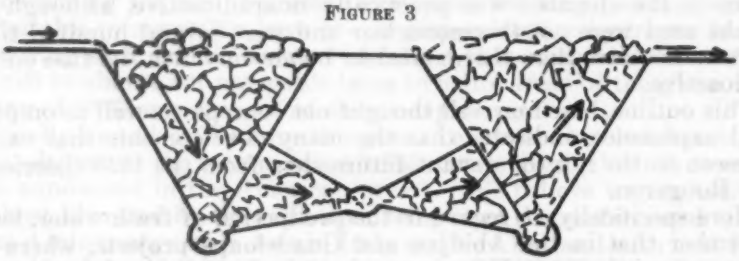

FIGURE 3.—Thermosyphon circulation of water in thermonuclear craters. In projects such as this one, where two large craters opening at the surface have been linked together by a smaller explosion, circulation is established automatically between the crater fed by cold water and the one from which the water is drawn out. If the depth is 2000 m. and the water goes down at an average temperature of 40° and goes up to an average of 60°, the difference in density, 0.992 and 0.978, allows the water to rise 28 m. above the level where it entered.

RECENT DEVELOPMENTS IN THE USE OF WIND POWER

E. W. Golding

Developments, during the last four years, in connection with the use of wind power can be placed under the following headings:

(*a*) Surveys and utilization studies;
(*b*) Wind powerplant of small capacity;
(*c*) Wind powerplant of medium capacity;
(*d*) Wind powerplant of large capacity.

These will be discussed in the order given.

(*a*) *Surveys and utilization studies*

In Great Britain the general wind survey to find available sites has been concluded but wind measurements are still being continued at a few key sites to provide long-term records. Studies of wind structure at various heights up to 1,200 feet are being made but this work is mainly for the benefit of organizations interested in wind pressures on tall structures rather than for wind power purposes. Comprehensive observations are also being made on simultaneous wind-and-ice-

loadings on test spans of overhead transmission lines in the Highlands of Scotland. Both of these research projects can be regarded as "by-products" of the extensive work done by the Electrical Research Association on various aspects of wind power during the preceding 10 years.

Widespread interest in the possibilities of windpower continues. Frequent enquiries are received from many parts of the world and new research groups are being formed. In the winter of 1957–58, the writer visited Uruguay, under the auspices of UNESCO, to initiate a wind survey and to give advice on wind power studies. A UNESCO Fellow from Burma spent some 4 months with the Electrical Research Association during 1958 for training in wind power work: he was a member of an officially sponsored wind power research team in Burma. A wind power committee is undertaking experimental work on various aspects of the subject in India and studies on the possibilities of using wind power for water pumping are being made in Pakistan (near Quetta) with support from UNESCO. In the autumn of 1959 the writer spent 5 weeks in Egypt to advise the Government on wind power studies, particularly in connection with water pumping in desert areas. This visit was sponsored by WMO/United Nations.

Wind survey work is also continuing in Israel where research on wind structure at various heights above different terrains is being done. Surveys have also been continued in South Australia, Trinidad, and Tobago, and other countries.

(*b*) *Wind power plant of small capacity*

Many thousands of small wind-driven generators, of capacity up to 3 or 4 kW, are in use in different parts of the world but developments have been in improved methods of using such plants for different purposes rather than in new designs. Machines of this range of size have been used for cathodic protection in Israel, Algeria, and the U.S.S.R., but little information is so far available on their success for this purpose.

The Electrical Research Association has operated, for nearly 2 years in the Highlands of Scotland, an 8 kW wind-driven generator of German design. This machine has been installed at a large house located on high ground and the experiment has been concerned with the full utilization of the energy produced without involving more than a relatively small storage battery. An automatic loading device has been developed to ensure that random energy is fed to one or more of the loads in the house and its surrounding buildings. Priorities for these loads are arranged by preselector equipment of a novel design. This experiment has been very successful and it has been found possible to supply most of the energy needs of an isolated house with limited storage capacity. It has been found, also, that the energy output from the machine has been significantly greater than was estimated from previous wind measurements at the site. This is because the estimation was made on the assumption of constant efficiency whereas the efficiency is, in fact, greater at fractional loads than at full load. This effect has been observed in the experimentally operated machines, of medium and large capacity, mentioned in the two following sections.

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(*c*) *Wind power plant of medium capacity*

A 25 kW wind-driven generator, connected to an alternating current network, has been operated experimentally in the Isle of Man for 18 months. Some modifications to the design have been found necessary but the test results show that the machine generates its full power at the design wind speed.

Wind power work has continued in U.S.S.R. mainly on plant of medium size. A 10½ kW machine was exhibited at the Leipzig Fair in 1956. This and other machines of similar size are intended mainly for use at the agricultural settlements in Russia.

(*d*) *Wind power plant of large capacity*

In Great Britain, following past work on two 100 kW pilot plants of different designs—one of which is now being operated experimentally, near to Algiers, by Electricité et Gaz d'Algérie—experimental work on windmill structures, covering a wide field, has been done at the E.R.A. windmill research station at Cranfield, Bedfordshire. This work has been supported by the Ministry of Power and, as a result, a new design for a 100 kW prototype has emerged. This prototype has been built and installed in the Isle of Man where, since November 1959, it has been running in connection to the alternating current network on the island. Tests on it are continuing but have so far shown satisfactory results and it has been proved that the machine generates its full output of 100 kW at the design wind speed. It is important to notice that the cost, per kW, of this machine, which is of simple and robust design, is very close to that which was estimated, at the outset of the British wind power research, to be the economic price.

The German wind power committee (Studiengesellschaft Windkraft) has also developed a 100 kW machine which has successfully undergone its preliminary tests at their research station near Göppingen.

In Denmark, the Danish wind power committee, on whose behalf the South East Zealand Electricity Company (S.E.A.S.) have been mainly responsible for the construction of a 100 kW wind-driven generator, is continuing its work. This machine, in the testing of which the British Electrical Research Association collaborated, has now been operating successfully in connection to the alternating current network for a period of some 2 years.

Two machines, one of 132 kW and one of 640 kW, of different designs, have been built in France and are now undergoing preliminary tests. No results have yet been published.

All the machines mentioned in this section are being used to supply energy to existing alternating current networks.

TEXT OF A LETTER FROM F. DANIELS

Your letter of February 26 has been forwarded to me while I am on an extended trip for the National Academy of Sciences, conferring with the scientists and many government officials in the Asian countries. I have taken this opportunity to explore the possibilities of using solar energy in Asia.

Each country has different problems and different potentialities, but I am convinced that solar energy utilization can do much for this part of the world. I am now spending most of my time on this research at the University of Wisconsin, with the help of a grant from the Rockefeller Foundation for research on the utilization of solar energy, with particular emphasis on trying to help the nonindustrialized countries.

As a supplement to my article on solar energy utilization in the United Nations publication on "New Sources of Energy and Economic Development," I will state that slow but steady progress has been made in research and that the most promising new development is the generation of electricity by focussing sunlight on thermocouples made of new semiconductors. This thermoelectric generation of electricity with focussed sunlight seems to offer the best means of using sunlight directly. Research in the Westinghouse laboratories and elsewhere indicates an efficiency of 10 percent in the conversion of solar radiation into electricity. The operation should be very simple and the materials should last indefinitely. Research on focussing reflectors of aluminized plastics have been carried out at the University of Wisconsin.

Steam engines operated with focussed sunlight do not look attractive because their efficiencies are so low. Hot air engines appear much more hopeful. Research on these is progressing.

The problem of converting sunlight into electricity has been solved technologically with the Bell Telephone Co.'s silicon photovoltaic cell, but it is impossibly expensive for ordinary use.

A book on the "Photochemistry in the Liquid and Solid States" is being published this month. It is based on a symposium called for the photochemical storage of energy. It records progress in photochemistry and gives "ground rules" for solar research in photochemistry.

The fields of solar energy utilization include:

solar cooking;
solar water heating;
solar drying of juices and foods;
solar house heating;
solar refrigeration;
solar air conditioning;
solar distillation of salt water;
solar generation of electricity;
storage of heat;
storage of electricity.

Solar cooking is being tested now in Mexico under the supervision of anthropologists in a program of the University of Wisconsin with 50 cookers.

There is a great need in Pakistan and India, and in all the Asian countries, for the solar pumping of water for irrigation.

There is need in many places, particularly on small islands, for the distillation of salt water.

Refrigeration and air conditioning with the sun would be popular in many hot countries.

The solar generation of electricity could be used with a storage battery for electric lighting at night, or for village industries.

All these things are definitely possible. The problem is to reduce costs through further research and to adapt the program to the special needs in each country. The research is not expensive and should be taken up by many of the nonindustrialized nations, particularly in Asia.

Some of these countries are planning to spend large sums for atomic energy research, at the sacrifice of support for other important research projects. For the present, a modest investment in solar energy research might be wiser.

A new book on research on solar energy throughout the world has been published by the Association for Applied Solar Energy.

EXTRACTS OF CORRESPONDENCE ADDRESSED TO THE SOVIET UNION BY SENATOR CLINTON P. ANDERSON, CHAIRMAN, JOINT COMMITTEE ON ATOMIC ENERGY

During visits with Professor Emelyanov both in Moscow on September 29, 1959, and here in the United States during his tour of atomic energy installations, my colleagues and advisers on the Joint Committee on Atomic Energy explored the feasibility of a cooperative inquiry into the role of atomic energy in advancing science and technology, standards of living and human welfare, and international cooperation. We have been encouraged by these conversations to seek an information cooperation. In some measure, this exchange of information is being forwarded directly by Professor Emelyanov, insofar as purely atomic matters are involved.

As you know I have appointed Mr. Robert McKinney, former U.S. representative to the International Atomic Energy Agency, to undertake a review and appraisal and to submit recommendations concerning the role of atomic energy in international affairs. Mr. McKinney also chaired a special Panel on the Impact of the Peaceful Uses of Atomic Energy, which reported to the Joint Congressional Committee on Atomic Energy in January 1956.

In undertaking this current study, Mr. McKinney has observed that the prospective role of atomic power must be examined in the context of energy resources and energy demand forecasts for all parts of the world. We, therefore, seek to obtain for the study completely current data on conventional energy resources and forecasts of overall energy demand for every important geographical area. Your assistance in obtaining for us such data covering the Soviet Union would be deeply appreciated. Needless to say, we fully appreciate that without a current statement of economically recoverable reserves of coal, oil, and gas, of current and projected rates of production of these fuel resources, and of energy demand forecasts for the Soviet Union, our study will be less complete and less useful to us all. Copies of Mr. McKinney's previous study and of a recent speech outlining this undertaking are enclosed for your information and guidance in helping us now. It would be helpful if the data could be presented in a form similar to the tables on pages 75 and 82 in volumn II of the 1956 report.

We are addressing similar requests for assistance to other countries and to various regional and international organizations of which the United States is a member or participant.

Of course, all of this information, all of the views and the recommendations will be openly available as a basis for our mutual consideration upon completion of the study in June 1960. We look forward to your cooperation in this undertaking which could result in a truly significant contribution to the advancement of peace, human welfare, and international cooperation through science and technology.

DECEMBER 11, 1959.

On December 11, 1959, I wrote requesting your assistance in assembling current and prospective conventional energy resource estimates and energy demand forecasts in connection with the review of international atomic policies and programs of the United States. Since I have not as yet received a reply to that request, I again solicit your cooperation in this undertaking.

It is our present intention to assemble all of this information, gathered both from public and private agencies in the United States and in other countries and from various international organizations, for publication in early June of this year. For your data and statements to be included, it will be necessary to have them in our hands not later than May 15.

Because of the very great importance of making available the best possible complete statement of world energy resources to all governments as an aid in developing proper policies and programs with regard to atomic power, I continue to hope that we will receive from you the data, estimates, and forecasts requested.

A copy of my letter of December 11, 1959, is enclosed.

APRIL 19, 1960.

In your letter of April 18, 1960, you requested the Department to transmit, through appropriate channels, letters from Senator Clinton P. Anderson to Soviet Ambassador Menshikov and Professor Emelyanov. These letters inquired as to the status of the Soviet replies to earlier letters from Senator Anderson requesting Soviet cooperation in providing certain information and data relating to the peaceful uses of atomic energy and conventional energy resources in the Soviet Union for use in Mr. McKinney's review. I enclose copies of a note from the Soviet Embassy dated May 6, 1960, in reply to our notes transmitting Senator Anderson's letter to the Soviet Embassy.

I have not enclosed a copy of the enclosure to the Soviet note, a report by Professor Emelyanov entitled "The Future of Atomic Power in the USSR," since it was received in the Russian language. The English language version is included in the published proceedings of the Second United Nations Conference on the Peaceful Uses of Atomic Energy (document reference number A/Conf.15/P/2027). I understand the published proceedings are readily available to the Review Staff.

UNITED STATES DEPARTMENT OF STATE,
MAY 17, 1960.

TEXT OF SOVIET UNION NOTE TO THE DEPARTMENT OF STATE

[Embossed Seal of the USSR]
Embassy of the Union of
Soviet Socialist Republics
No. 56–N

In connection with the notes dated December 24, 1959, and April 26, 1960, from the Department of State of the USA, the Embassy of the USSR is sending herewith a report by V. S. Yemelyanov, Chief of the Main Administration on the Use of Atomic Energy at the Council of Ministers of the USSR, concerning the future of atomic power in the USSR, which was presented at the 2nd International Conference of the UN on the Peaceful Use of Atomic Energy, for transmission to Senator Clinton P. Anderson, Chairman of the Joint Congressional Committee on Atomic Energy. It is not possible to comply with Senator Clinton P. Anderson's request for data on the ordinary power resources of the Soviet Union with a forecast for the future, inasmuch as there is at present no generalized published data on this question.

Enclosure: the report by V. S. Yemelyanov entitled *The Future of Atomic Power in the USSR.*

WASHINGTON, MAY 6, 1960.

[Initialed]
Department of State,
United States of America,
Washington, D.C.

EDITOR'S NOTE.—Enclosure was the Russian text of a speech, previously published in English in the proceedings of the 1958 United Nations Conference on the Peaceful Uses of Atomic Energy at Geneva.

STAFF NOTE.—The following staff memorandum has been prepared on conventional energy resources of Communist countries:

PRODUCTION AND RESERVES OF PRIMARY ENERGY IN THE SINO-SOVIET AREA, 1959, 1975, AND 2000

INTRODUCTION

As in all reports on the Sino-Soviet Area economy, the variations in the availability and quality of data vary widely from country to country. Data on the primary energy industries of the U.S.S.R. are voluminous by comparison to information on China's fuels; and within the European Satellite nations,[1] the variations in available data are extreme. However, in comparison to the statistical information on Free World energy, even the data on the Soviet Union must be regarded as fragmentary.

In contrast to the comprehensive and detailed forecasts of energy resources in the Free World which will appear in the "Review of International Atomic Policies and Programs of the United States," the review of the Sino-Soviet Area can attempt only to highlight some of

[1] Including Albania, Bulgaria, Czechoslovakia, East Germany, Hungary, Poland, and Rumania.

the major aspects of the energy reserve picture, to indicate major trends in production, and to generalize about some features of the energy balance through the remainder of the Twentieth Century. Little or no firm data on production costs, for example, are available for any of the countries except the U.S.S.R.; but such data as are available on the Soviet Union can be projected, at best, only for the end of the Seven Year Plan period (1959–1965). Data on either current or future price levels of primary energy in the Sino-Soviet Area are regarded as useless for the purposes of this particular study. Moreover, it has been demonstrated that the level of activity which might obtain in any given sector of the Sino-Soviet Area economy is not necessarily determined by cost-price relations. Decisions by planners that an activity is in the national interest can be the raison d'etre for operations which are incomprehensible to those normally conditioned to economic activity based on profits and losses.

RESERVES OF PRIMARY ENERGY

The Soviet Union: The primary energy reserves of the U.S.S.R., exclusive of hydroelectric resources, are estimated at almost 7 trillion tons of standard fuel.[2] Only slight diminution of primary energy reserves is anticipated for the future (see Table 1). Coal constitutes by far the largest portion of the fuel resources of the U.S.S.R. Even considering that the most recent official estimate (1957) indicated that less than 5 percent of the total coal may fall in the category of proved reserves, it is believed that the U.S.S.R. has an almost inexhaustible reserve of this fuel.

In addition to its vast resources of coal, the U.S.S.R. has reserves of peat and oil shale which can be estimated at roughly 70–80 billion tons of standard fuel. As in the case of coal, however, the Soviet Union is still in the process of surveying its raw material resources; and what the ultimate limits of peat and oil shale may be is unknown.

By the end of the century, significant increases are anticipated in the proved reserves of both crude petroleum and natural gas—petroleum increasing from an estimated 5.6 billion tons of standard fuel in 1959 to about 21.5 billion tons in 2000 and natural gas from about 2 billion tons to 24 billion tons in the same period. The data upon which such estimates are based render invalid any percentage breakdown of these fuels in relation to total primary energy resources. Since the Soviet Union is planning tremendous expansions in both petroleum and natural gas production (see subsequent discussion of energy production), it is possible that the estimates of petroelum and natural gas reserves presented in Table 1 represent minimum rather than maximum resources.

The determination of hydroelectric resources in any country, not excepting the USSR, is highly complex, involving among other factors, determinations about theoretical potential, technical potential, and economic potential. The USSR recently reported an annual economic hydroelectric potential, of 137 million kilowatts, and equated this to 1.2 trillion kilowatt-hours.[3] The accuracy of this survey and

[2] Standard fuel has a calorific value of 7,000 kilocalories per kilogram. All tons referred to in this paper are metric tons.

[3] This estimate assumes the highly improbable condition of a 100-percent plant factor (8,760 hours of operation annually).

the extent to which physical limiting factors such a permafrost, ice conditions, and accessibility were considered are unknown. In terms of theoretical potential, including the flow of minor rivers, the USSR claims to have in excess of 11 percent of the world's hydroelectric resources. In terms of a more realistic measure—economic potential—the hydroelectric resources of the Soviet Union may be about twice those of the United States.

From the nature of developments which have taken place thus far in the fuels industries of the Sovet Union, problems related to location, topography, climate, and such other natural factors as might bear on the successful exploitation of primary energy reserves should be regarded, for the most part, as temporary inconveniences rather than permanent obstacles. Like their Western contemporaries, the resource technicians of the USSR have demonstrated their competence in overcoming such obstacles. In short, it is believed that there are few of the energy resources which are likely to prove to be out of reach if the planners determine that they are required for successful expansion of industry in the Soviet Union.

The European Satellites: The primary energy resources of the European Satellite nations are infinitesimal in comparison with either the geological or proved reserves of the Soviet Union. Even with allowance for the many areas about which no data are available, the total energy reserves of the East European nations are estimated at a maximum of 35.4 billion tons of standard fuel. As with the USSR, reserves of coal (35 billion tons) constitute the largest share of the total. Both natural gas and petroleum reserves are relatively small, together amounting to only about 400 million tons of standard fuel. Hydroelectric power is insignificant in the overall picture.

Abundance of coal reserves notwithstanding, the nature of the energy demand in recent years in Eastern Europe has been for increasing quantities of petroleum. By 1975, about 20 percent of total energy demand probably will be for petroleum, a significant portion of which will have to be derived from imports.

Communist China: China possesses the only significant reserves of primary energy known to exist in the Asiatic portion of the Sino-Soviet Area.[4] Based on fragmentary data which undoubtedly have high margins of error, it is estimated that China has primary energy reserves equal to about 1.4 trillion tons of standard fuel. This would indicate that China's primary fuel reserves are equal to about 20 percent of those of the USSR.

As in other parts of the Sino-Soviet Area, the largest share (about 98%) of the energy reserve is composed of coal. Second to coal are oil shale reserves of more than 20 billion tons of standard fuel. Although relatively unimportant in the picture of total reserves, the hydroelectric potential of China, like that of the USSR probably will play a significant role in the economic development of China.

To date there is little reliable evidence upon which to base an estimate of China's natural crude oil reserves. Present estimates placed proved reserves of natural crude oil at 30 million tons and possible reserves at 1.3 billion tons. In addition reserves of oil shale could yield as much as 15 billion tons of oil.

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[4] China, North Korea, North Vietnam, and Mongolia. Neither North Korea nor North Vietnam has primary energy reserves of major size, and resources of Mongolia are an unknown quantity.

PRODUCTION OF PRIMARY ENERGY

The Soviet Union: As in the case of reserves, the Soviet Union is the major producer of primary energy in the Sino-Soviet Area; and as shown in Table 2, this will continue to be the case through the remainder of the century. Through 1965, the output of coal will exceed that of any other form of primary energy, but the share of coal in the energy balance of the Soviet Union will be altered radically in this period. The latest goals actually reported are for the Soviet Seven Year Plan (1959–1965), and the Plan makes it quite clear that both petroleum and natural gas are to be developed at the expense of coal. The sharp nature of the production increases in oil and gas are illustrated by comparing 1958 output with that anticipated for 1965:

Commodity	1958		1965	
	Output (million metric tons standard fuel)	Percent of total output	Output (million metric tons standard fuel)	Percent of total output
Coal	365.2	58.1	430.2	41.8
Petroleum	161.9	25.7	343.2	32.7
Natural gas and associated gas	33.7	5.4	177.9	17.0
Peat	20.0	3.2	27.0	2.6
Fuelwood (excluding losses)	24.9	4.0	25.7	2.4
Combustible shale	4.5	.7	7.5	.7
Hydroelectricity	18.2	2.9	29.5	2.8
Total	628.4	100.0	1,050.0	100.0

Based on the evidence thus far available, it is anticipated that by 1975 the output of crude petroleum will surpass that of coal by almost 150 million tons of standard fuel. By the end of the century production of petroleum, natural gas, and hydroelectric power, in standard fuel, will be well in excess of the output of coal. Although Table 2 indicates a tremendous spurt in the production of natural gas, the estimated outputs indicated for 1975 and 2000 (480 million and 1,200 million tons of standard fuel, respectively) may tend, in fact, to understate the case for the increased utilization of energy in this form.

Available data are inadequate for making any long-range predictions on future prices of primary fuels. Some brief examination of estimated production costs, however, will provide additional insight into the developments which are helping to bring about the radical alterations in the energy-producing industries.

It is possible to estimate that average production costs per ton of standard fuel in the U.S.S.R. will be reduced approximately 30 rubles between 1958 and 1965, from about 80 rubles in 1958 to 50 rubles in 1965. About two-thirds (20 rubles) of this reduction can be attributed to the increased share of petroleum and natural gas in the energy balance at the expense of coal production. The share of oil and natural gas in the total energy balance will increase from approximately one-third in 1958 to over one-half in 1965, where as the share of coal will decline, during the same period, from approximately two-thirds to less than one-half.

The remaining 10 rubles per ton of standard fuel saved in 1965 (compared to the 1958 cost) will result from lower production costs. A reduction of only about 10 percent in coal production costs in 1965 compared to 1958 will account for over half of the ten ruble total saving. Reductions of approximately 30 percent for oil and natural gas and 45 percent for hydroelectricity together will account for the remaining savings. Thus, relatively small reductions in coal costs have far greater effect on average energy costs than proportionately larger cost reductions for oil, natural gas, and hydroelectricity.

The combination of changes in the proportions of each type of fuel in the energy balance plus anticipated reductions in the costs of production of all major types of primary energy in the U.S.S.R. probably will continue well after 1975, but it is impossible to forecast the average production cost per ton of standard fuel by the close of this century.

Prognosticating the overall supply-demand balance of primary energy in the Soviet Union is an infeasible task, and is perhaps best resolved by assuming that domestic fuel requirements in the U.S.S.R., at whatever level, probably can be satisfied from domestic production. As an example of the complexities of this problem, the U.S.S.R. probably will become an ever-growing exporter of crude oil and petroleum products—a trend which has been developing since the mid-1950's. Since that time the Free World has been the major recipient of Soviet petroleum exports. This probably will continue to be the case until 1965. What the nature of the distribution of Soviet exports to the Free World and to other members of the Sino-Soviet Area might be after 1965 is impossible to ascertain. Marked increases in the petroleum requirements of the European Satellites or realization of expected sizable expansion of Western European oil holdings in Africa will have a direct effect on the nature of Soviet petroleum trade.

The European Satellites: As indicated in Table 2, the output of the major types of primary energy is going to increase significantly between now and the close of the century. By that time, compared to 1958 output, coal production will about double, crude petroleum will increase about two and one half times, and natural gas will be tripled (all measured in standard fuel). Imports of petroleum from the Soviet Union have been important for fulfillment of economic plans in the European Satellites in recent years. Achievement of current industrialization plans in Eastern Europe will require significant increases in imports of petroleum from the U.S.S.R. and may reduce the quantity of Soviet petroleum available for export to the Free World.

Communist China: Present forecasts of future petroleum production in Communist China indicate an output of 15 million tons in 1967 and of 45 million tons in 1972. No estimates of future production have been attempted for any year beyond 1972. It is unlikely that serious energy shortages during the next forty years will be attributable to a lack of reserves. Such shortages as may occur are more likely to be of a temporary nature and probably will not result in a serious imbalance in the primary energy supply-demand situation.

TABLE 1.—*Estimated primary energy reserves of the Sino-Soviet area, 1959, 1975, 2000*

	U.S.S.R.		European satellites [3]		Communist China [4]		Total	
	Natural units [1]	Standard fuel [2] (billion metric tons)	Natural units	Standard fuel (billion metric tons)	Natural units	Standard fuel (billion metric tons)	Natural units	Standard fuel [5] (billion metric tons)
Coal:								
1959	[6] 8,670.0	[7] 6,900.0	[8] 70.0	[9] 35.0	[10] 1,500.0	[11] 1,400.0	10,240.0	8,335.0
1975	[6] 8,670.0	[7] 6,700.0	75.0	[9] 35.0	[10] 1,500.0	[11] 1,400.0	10,245.0	8,135.0
2000	[6] 8,670.0	[7] 6,600.0	70.0	[9] 34.0	[10] 1,500.0	[11] 1,400.0	10,240.0	8,034.0
Shale:								
1959	[12] 60.0	[13] 17.0	(14)	(14)	[15] 360.0	[16] 22.5	420.0	39.5
1957	[12] 60.0	[13] 17.0	(14)	(14)	[15] 360.0	[16] 22.5	420.0	39.5
2000	[12] 60.0	[13] 17.0	(14)	(14)	[15] 360.0	[16] 22.5	420.0	39.5
Peat:								
1959	[17] 158.0	[18] 60.0	(19)	(19)	(19)	(19)	158.0	60.0
1975	[17] 158.0	[18] 56.0	(19)	(19)	(19)	(19)	158.0	56.0
2000	[17] 158.0	[18] 54.0	(19)	(19)	(19)	(19)	158.0	54.0
Crude petroleum:								
1959	[20] 3.9	[21] 5.6	[22] .2	[23] .3	(24)	(24)	4.1	5.9
1975	[20] 9.5	[21] 13.5	.3	[23] .4	[25] [26] 1.3	[27] 1.9	11.1	15.8
2000	[20] 15.0	[21] 21.5	.3	[23] .5	(19)	(19)	15.3	22.0
Natural gas:								
1959	[28] 1,500.0	[29] 1.8	[30] 850.0	[31] 1.1	(14)	(14)	2,350.0	1.9
1975	[28] 8,000.0	[29] 9.6	900.0	[31] 1.1	(14)	(14)	8,900.0	9.7
2000	[28] 20,000.0	[29] 24.0	1,000.0	[31] 1.1	(14)	(14)	21,000.0	24.1
Hydroelectricity:								
1959	[32] 1,200.0	(33)	[34] 80.0	(33)	[35] 1,000.0	(33)	2,280.0	(33)
1975	[32] 1,200.0	(33)	80.0	(33)	[35] 1,000.0	(33)	2,280.0	(33)
2000	[32] 1,200.0	(33)	80.0	(33)	[35] 1,000.0	(33)	2,280.0	(33)
Total:								
1959		6,984.4		35.4		1,422.5		8,442.3
1975		6,796.1		35.5		1,424.4		8,256.0
2000		6,716.5		34.6		1,422.5		8,173.6

[1] Natural units for all countries given as follows: Natural gas, billions of cubic meters; hydroelectricity, billions of kilowatt-hours; all others, billion metric tons.

[2] Standard fuel refers to a unit of measure based on calorific value. Standard fuel has a value of 7,000 kilocalories per kilogram.

[3] Includes reserves of following countries: Albania, Bulgaria, Czechoslovakia, East Germany, Hungary, Poland, and Rumania.

[4] Reserves of North Korea and North Vietnam are excluded as insignificant. Mongolia is excluded because of lack of data.

[5] Totals include all figures listed for 1959, 1975, and 2000, regardless of the actual year of the data as explained in these footnotes.

[6] Estimated geological reserves for 1957 of all types of coal, including about 240,000,000,000 metric tons of proved reserves, 940,000,000,000 metric tons of probable reserves, and about 7,500,000,000,000 metric tons of possible reserves. The ratios probably will change during the 1959–2000 period, with increases being anticipated in both proved and probable categories and a decline is expected in possible reserves. For purposes of this report the overall totals for both 1975 and 2000 are assumed at least equal to 1957.

[7] Calorific value of coal reserves in the U.S.S.R. has been estimated as follows: 1959, 5,570 kilocalories per kilogram; 1975, 5,425 kilocalories per kilogram; 2000, 5,355 kilocalories per kilogram.

[8] As of Jan. 1, 1959.

[9] Calorific value of coal reserves in the European satellites has been estimated as follows: 1959, 3,460 kilocalories per kilogram; 1975, 3,230 kilocalories per kilogram; 2000, 3,375 kilocalories per kilogram.

[10] Assumed geological reserves of which 80,000,000,000 tons are indicated as "proved" reserves. It is estimated that reserves in 1975 and 2000 will be at least equal those of 1959.

[11] Calorific value of coal reserves in Communist China has been estimated at 6,500 kilocalories per kilogram for all years.

[12] Estimated proved reserves for 1946. It is anticipated that reserves may be increased significantly during the period 1959–2000, but since it is impossible to determine to what level, it has been assumed that they would at least equal 1946.

[13] Calorific value of shale reserves in the U.S.S.R. has been estimated at 2,000 kilocalories per kilogram in all years.

[14] Negligible.

[15] Probably geological reserves. Estimates for 1975 and 2000 assume that minimum reserves will be at least equal to 1959.

[16] Estimate based on claim that indicated reserves could yield 15,000,000,000 tons of oil. This would indicate 24 tons of oil shale per ton of oil. Calorific value of petroleum is estimated as 10,500 kilocalories per kilogram, or 1.5 tons of standard fuel per ton of oil.

[17] Estimated proved reserves for 1957 and presumed to represent air-dried peat with a 30-percent moisture content. Assumes that minimum reserves in 1975 and 2000 will be at least as great as in 1957.

[18] Calorific value of peat in the U.S.S.R. has been estimated as follows: 1959, 2,640 kilocalories per kilogram; 1975, 2,485 kilocalories per kilogram; 2000, 2,380 kilocalories per kilogram.

[19] Not available.

Footnotes continued on p. 1650.

Footnotes continued from p. 1649.

[20] Estimated proved reserves based on ratio of reserves to crude production of 30 to 1 in 1959; 20 to 1 in 1975; and 15 to 1 in 2000.
[21] Calorific value of crude petroleum in the U.S.S.R. has been estimated at 10,010 kilocalories per kilogram in all years.
[22] As of Jan. 1, 1959.
[23] Calorific value of crude petroleum in the European satellites has been estimated as follows: 1959, 9,850 kilocalories per kilogram; 1975, 10,330 kilocalories per kilogram; 2000, 10,500 kilocalories per kilogram.
[24] Negligible.
[25] Proved reserves of natural crude oil reported as 30,000,000 tons in 1959.
[26] Estimated on basis of ratio of reserves to production of about 30 to 1, roughly the same ratio as for the U.S.S.R. in 1959.
[27] Calorific value of petroleum 10,500 kilocalories per kilogram, or 1.5 tons of standard fuel per ton of petroleum.
[28] Nonassociated natural gas only.
[29] Calorific value of natural gas reserves in the U.S.S.R. have been converted to standard fuel at the rate of 1.2 tons of standard fuel (8,400 kilocalories per kilogram) per 1,000 cubic meters of natural gas.
[30] As of Jan. 1, 1959.
[31] Calorific value of natural gas in the European satellites has been estimated at 1.3 tons of standard fuel (9,100 kilocalories per kilogram) per 1,000 cubic meters of natural gas.
[32] Estimated annual economic potential 1957. Assumes that the annual economic potential in both 1975 and 2000 will be at least as great as in 1959.
[33] Not applicable.
[34] As of Jan. 1, 1959.
[35] Figure indicated is presumed to be annual economic potential for 1967 and is assumed reasonable for 1959 and 2000.

TABLE 2.—*Estimated production of primary energy in the Sino-Soviet area, 1959, 1975, 2000*

	U.S.S.R.		European satellites [2]		Communist China [4]		Approximate total	
	Natural units [1]	Standard fuel [2] (million metric tons)	Natural units	Standard fuel (million metric tons)	Natural units	Standard fuel (million metric tons)	Natural units	Standard fuel [5] (million metric tons)
Coal:								
1959	[6] 506.5	[7] 403.2	[8] 447.0	[9] 221.0	348.0	[10] 323.0	1,301.5	947.2
1975	700.0	[7] 540.0	752.0	[9] 347.0	[11] 900.0	[10] 836.0	2,352.0	1,723.0
2000	775.0	[7] 590.0	861.0	[9] 415.0	[12]	[12]	1,636.0	1,005.0
Shale:								
1959	13.7	[13] 4.0	[12]	[12]	[12]	[12]	13.7	4.0
1975	40.0	[13] 12.0	[12]	[12]	[12]	[12]	40.0	12.0
2000	65.0	[13] 20.0	[12]	[12]	[12]	[12]	65.0	20.0
Peat:								
1959	55.0	[14] 20.0	[8] [15] 27.0	[16] 6.0	[12]	[12]	82.0	26.0
1975	55.0	[14] 20.0	[12]	[12]	[12]	[12]	55.0	20.0
2000	55.0	[14] 20.0	[12]	[12]	[12]	[12]	55.0	20.0
Crude petroleum:								
1959	[8] 129.5	[17] 185.0	[8] 13.5	[18] 19.0	3.6	[19] 5.4	146.6	209.4
1975	475.0	[17] 680.0	21.0	[18] 31.0	[11] 45.0	[19] 68.0	541.0	779.0
2000	1,000.0	[17] 1,400.0	28.0	[18] 42.0	[12]	[12]	1,028.0	1,442.0
Natural gas:								
1959	[20] 37.2	[21] 45.0	[8] 10.0	[22] 13.0	[12]	[12]	47.2	58.0
1975	400.0	[21] 480.0	23.5	[22] 32.0	[12]	[12]	423.5	512.0
2000	1,000.0	[21] 1,200.0	30.0	[22] 39.0	[12]	[12]	1,030.0	1,239.0
Hydroelectricity:								
1959	[23] 46.5	[24] 20.4	[8] 5.0	[25] 2.0	[12]	[12]	51.5	22.4
1975	320.0	[26] 108.8	31.0	[25] 12.0	[26] 100.0	[27] 40.0	451.0	160.8
2000	2,700.0	[24] 770.0	40.0	[25] 16.0	[12]	[12]	2,740.0	786.0
Approximate total:								
1959		677.6		261.0		328.4		1,267.0
1975		1,840.8		422.0		944.0		3,206.8
2000		4,000.0		512.0		[12]		4,512.0

[1] Natural units for all countries given as follows: Natural gas, billion cubic meters; hydroelectricity billion kilowatt-hours; and all the others, million metric tons.

[2] Standard fuel refers to a unit of measure based on calorific value. Standard fuel has a value of 7,000 kilocalories per kilogram.

[3] Includes production from following countries: Albania, Bulgaria, Czecholsovakia, East Germany, Hungary, Poland, and Rumania.

[4] Production from North Korea and North Vietnam are minor. The 1964–65 production goals for North Korea indicate 25,000,000 tons of coal and 20,000,000,000 kilowatt-hours of electric energy (mostly hydroelectricity).

[5] Totals include all figures listed for 1959, 1975, and 2000, regardless of the actual year of the data as explained in the footnotes.

[6] Announced achievement.

[7] Calorific value of coal produced in the U.S.S.R. has been estimated as follows: 1959, 5,570 kilocalories per kilogram; 1975, 5,425 kilocalories per kilogram; 2000, 5,355 kilocalories per kilogram.

[8] Estimate for 1958.

[9] Calorific value of coal produced in the European satellites has been estimated as follows: 1959, 3,460 kilocalories per kilogram; 1975, 3,230 kilocalories per kilogram; 2000, 3,375 kilocalories per kilogram.

[10] Calorific value of coal produced in Communist China has been estimated at 6,500 kilocalories per kilogram for all years.

[11] Planned goal for 1972.

[12] Not available.

[13] Calorific value of shale produced in the U.S.S.R. has been estimated at 2,000 kilocalories per kilogram in all years.

[14] Calorific value of peat produced in the U.S.S.R. has been estimated as follows: 1959, 2,640 kilocalories per kilogram; 1975, 2,485 kilocalories per kilogram; 2000, 2,380 kilocalories per kilogram.

[15] Includes both peat and fuelwood.

[16] Calorific value of peat produced in the European satellites has been estimated as 1,555 kilocalories per kilogram in 1958.

[17] Calorific value of crude petroleum produced in the U.S.S.R. has been estimated at 10,010 kilocalories per kilogram in all years.

[18] Calorific value of crude petroleum produced in the European satellites has been estimated as follows: 1959, 9,850 kilocalories per kilogram; 1975, 10,330 kilocalories per kilogram; 2000, 10,500 kilocalories per kilogram.

[19] Calorific value of crude petroleum produced in Communist China has been estimated at about 10,500 kilocalories per kilogram.

[20] Announced as total gas output, presumably including manufactured gas.

[21] Natural gas produced in the U.S.S.R. has been converted at the rate of 1.2 tons of standard fuel (8,400 kilocalories per killigram) per 1,000 cubic meters of natural gas.

[22] Calorific value of natural gas produced in the European satellites has been estimated at 1.3 tons of standard fuel (9,100 kilocalories per kilogram) per 1,000 cubic meters of natural gas.

[23] Announced achievement for 1958.

[24] Standard fuel requirements are estimated to be roughly as follows: 0.45 ton per 1,000 kilowatt-hours in 1958; 0.34 tons per 1,000 kilowatt-hours in 1975; and 0.29 ton per 1,000 kilowatt-hours in 2000.

[25] Standard fuel requirements are estimated to be about 0.4 ton per 1,000 kilowatt-hours in all years.

[26] Planned goal for 1967.

[27] Standard fuel requirements estimated roughly as 0.4 ton per 1,000 kilowatt-hours.

LETTER REQUEST TO FEDERAL POWER COMMISSION

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Accordingly, it would be greatly appreciated if the Federal Power Commission could make for us new forecasts of energy requirements of the United States similar to the forecast made for the earlier study, although this time making a forecast first for the period 1959–1975 and then for the period 1975–2000—that is, for 15 and 40 years ahead. * * *

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LETTER OF TRANSMITTAL FROM FEDERAL POWER COMMISSION

In answer to your letter * * * we are enclosing a copy of Federal Power Commission Release No. 10,480 which gives forecasts of energy requirements of the United States by regions to the year 1980. This release furnishes data similar to that supplied in connection with your earlier study.

As for the year 2000, we have made no comprehensive analysis of requirements so far ahead. Extension of trends on an arbitrary basis indicates that electric utility energy requirements may be in the neighborhood of 4 to 5 trillion kilowatt-hours requiring from 800 million to a billion kilowatts of generating capacity. In addition, industrial plants with generating capacity of their own may produce roughly 200 billion kilowatt-hours from capacity in the order of 40 million kilowatts.

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FEDERAL POWER COMMISSION RELEASE FOR PUBLICATION

Immediate Release

Release No. 10,480
(PUB)

NEW ESTIMATES BY FPC STAFF INDICATE NATION'S ELECTRIC UTILITY POWER LOADS WILL REQUIRE 421 MILLION KILOWATTS OF INSTALLED GENERATING CAPACITY IN 1980

Washington, D. C., June 17, 1959 -- New estimates prepared by the staff of the Federal Power Commission indicate that peak demand requirements on electric utility systems in the United States will reach 366 million kilowatts by 1980, making necessary an installed generating capacity of 421 million kilowatts.

This compares with a peak of 120 million kilowatts in 1958, with 142 million kilowatts of capacity at the end of the year. The addition of industrially owned establishments brings the total needed capacity of the country in 1980 up to approximately 451 million kilowatts, compared with the 1958 year-end total of 160 million.

The new estimates were prepared by the FPC staff as revisions of forecasts published in June of 1958. Last year's forecasts appeared in a report entitled "Electric Power Requirements and Supply of the United States by Regions - Present and Future to 1980." The newly revised estimates are attached to this release and will not appear in any other published form.

The new figures are higher than the previous estimates despite the fact that electric power growth in 1958 was not as great as expected. The staff pointed out that during some periods of the year, power consumption was actually less than in 1957. However, it said, growth so far during 1959 has been better than normal and it does not appear now that long term future growth will be adversely affected by the 1958 experience. The staff noted that even though the rate of power consumption declined in 1958, generating capacity additions set an all time high of nearly 14 million kilowatts.

The staff said that an important factor in the upward revision of the forecasts was the release in 1958 of new population projections by the Census Bureau. The staff uses the highest series of population projections published by the Census Bureau in preparing estimates of future electric loads, and the latest such figures for 1980 are more than nine percent above those indicated in the previous Census study. The revised forecasts of 1980 electric energy requirements are about eight percent above those in last year's report.

Among the major sales classifications, nonfarm-residential energy requirements in 1980 have been increased 12 percent over the previous figures, commercial requirements 13 percent, and industrial 5 percent. Total electric utility energy requirements in 1980 are estimated to be slightly over two trillion kilowatt-hours, or nearly 3.1 times the 1958 requirements of 651 billion kilowatt-hours.

The utility capacity in 1980 is expected to consist of 57 million kilowatts in hydroelectric installations, about 356 million in steam plants, including nuclear, and nearly 8 million in internal combustion stations. Total capacity, including both utility and industrial, would be approximately 58 million in hydroelectric, 382 million in steam, and 11 million in internal combustion.

Details of the revised estimates appear in the attached tables.

-FPC-

Table 1

ENERGY REQUIREMENTS OF ELECTRIC UTILITIES BY CLASS OF USE

Billion Kwh

(Alaska Not Included)

		Region								
	Year	I	II	III	IV	V	VI	VII	VIII	U.S.
Farm, excluding irrigation and drainage pumping	1957	1,942	3,614	4,903	4,526	2,154	1,349	1,760	758	20,906
	1958									22,369
	1980	3,895	8,414	10,394	8,308	5,415	4,386	3,468	1,452	45,732
Irrigation and drainage pumping	1957	0	0	11	0	576	217	1,285	5,911	8,000
	1958									8,000
	1980	0	0	20	0	1,519	1,203	5,770	10,304	18,816
Nonfarm-residential	1957	29,672	22,930	23,937	16,436	13,014	3,108	12,415	11,617	133,051
	1958									143,338
	1980	108,639	81,300	96,410	61,702	54,699	12,191	39,427	52,056	506,431
Commercial	1957	25,663	14,458	13,807	12,222	11,416	2,578	5,522	9,328	94,994
	1958									101,056
	1980	75,419	42,868	55,176	33,651	34,244	9,148	21,060	34,692	306,258
Industrial	1957	46,454	69,609	69,727	33,108	24,696	2,597	25,519	19,513	291,223
	1958									243,280
	1980	120,444	199,615	171,103	114,375	85,800	11,423	88,813	79,160	870,433
Street and highway lighting	1957	1,540	1,013	598	845	531	188	275	601	5,591
	1958									6,047
	1980	3,280	2,280	2,018	2,020	1,866	713	996	1,872	15,045
Electrified transportation	1957	3,003	338	68	569	52	6	223	143	4,402
	1958									4,051
	1980	3,705	180	49	645	11	0	310	125	5,025
Other deliveries to ultimate consumers	1957	3,444	2,813	2,168	1,882	2,543	427	666	3,241	17,184
	1958									18,680
	1980	8,022	7,329	5,701	4,100	6,535	1,435	2,474	7,071	42,667
Losses and unaccounted-for	1957	11,994	10,273	10,767	7,071	6,708	1,757	5,971	7,068	61,609
	1958									64,049
	1980	36,965	33,314	36,140	23,796	21,389	5,424	19,486	25,673	202,187
Total energy requirements	1957	123,612	125,048	125,906	76,661	61,690	12,227	53,636	58,180	636,960
	1958	127,121	124,490	130,249	77,517	65,296	13,214	52,187	60,828	650,900
	1980	360,369	375,300	377,011	248,597	211,178	45,930	181,804	212,605	2,012,794

NOTE: 1957 actual; 1958 preliminary actual (breakdown of regional figures not available); 1980 estimated.

NOTE: 1957 actual; 1958 preliminary actual (breakdown of regional figures not available); 1980 estimated.

Table 2

ELECTRIC UTILITY ENERGY REQUIREMENTS AND PEAK LOADS

Energy in Billion Kwh; Peaks 1/ in Thousand Kw

(Alaska Not Included)

	1957		1958		1960		1965		1970		1975		1980	
Region	Energy	Peak	Energy	Peak	Energy	Peak	Energy	Peak	Energy	Peak	Energy	Peak	Energy	Peak
I	123,612	23,322	127,121	25,155	153,250	28,944	193,787	36,303	240,984	44,818	297,362	54,965	360,369	66,280
II	125,048	20,980	126,690	22,034	155,140	26,913	203,539	35,703	254,272	44,770	312,123	55,069	375,300	66,266
III	125,906	21,656	130,249	22,272	154,673	27,386	207,532	36,980	260,016	46,659	314,721	56,712	377,011	68,078
IV	76,661	13,677	77,517	14,334	97,938	17,901	131,269	24,480	167,593	31,089	208,115	38,504	248,997	45,918
V	61,690	12,607	65,294	13,553	79,409	16,135	111,188	22,669	143,340	29,310	176,900	36,145	211,178	43,311
VI	12,227	2,460	13,214	2,716	16,675	3,382	23,017	4,569	30,780	5,945	39,690	7,526	45,930	8,640
VII	53,636	9,099	52,187	9,166	70,563	11,881	94,163	15,698	121,109	20,213	150,640	25,216	191,804	30,567
VIII	58,180	10,390	60,826	11,007	72,903	12,810	99,454	17,300	130,630	22,340	168,483	29,590	232,405	37,388
U.S.	636,960	114,191	690,900	120,267	799,513	145,252	1,064,067	193,496	1,348,624	245,744	1,667,634	303,727	2,012,994	366,280
2/	82,997		76,453		93,000		106,750		120,900		134,250		148,000	
3/	719,957		727,353		892,513		1,170,817		1,469,124		1,801,884		2,160,994	

NOTE: 1957 actual; 1958 preliminary actual; 1980 estimated.

1/ Each regional peak is the highest of the twelve monthly peaks for the particular region, and represents the sum of the noncoincidental utility system peaks during each high month. The peaks for the United States are the arithmetical sums of the regional peaks.

2/ U. S. monutility generation exclusive of deliveries to electric utilities (latter estimated at 2 billion kwh annually in future).

3/ U. S. total electric energy requirements.

Table 3

INSTALLED CAPACITY AND OUTPUT OF GENERATING PLANTS

(Alaska Not Included)

Electric Utilities

Region	Year end Capacity (Thousand Kw) Hydro	Steam	Internal Combustion	Total	Total Generation (Million Kwh)
			1957		
I	3,022	22,746	257	26,025	119,551
II	496	23,179	222	23,897	123,494
III	6,661	16,749	153	23,563	125,295
IV	1,058	14,506	658	16,222	76,109
V	998	12,097	795	13,890	62,063
VI	1,283	1,729	277	3,289	12,031
VII	8,718	981	60	9,759	54,109
VIII	4,800	7,555	123	12,478	58,855
U. S.	27,036	99,542	2,545	129,123	631,507
			1958 2/		
U. S.	29,363	110,435	2,615	142,413	644,760

1/ Including nuclear.

2/ Preliminary.

Industrial Establishments

Region	Year end Capacity (Thousand Kw) Hydro	Steam	Internal Combustion	Total	Total Generation (Million Kwh)
			1957		
I	351	3,416	96	3,863	14,000
II	131	4,137	124	4,392	21,582
III	71	2,162	24	2,257	12,088
IV	111	1,576	101	1,788	7,242
V	3	2,489	853	3,345	23,977
VI	9	188	13	210	677
VII	47	672	5	724	3,161
VIII	2	479	38	519	2,120
U. S.	725	15,119	1,254	17,098	84,849
			1958 1/		
U. S.	735	15,833	1,238	17,806	79,253

1/ Preliminary.

2/ Preliminary.

1/ Preliminary.

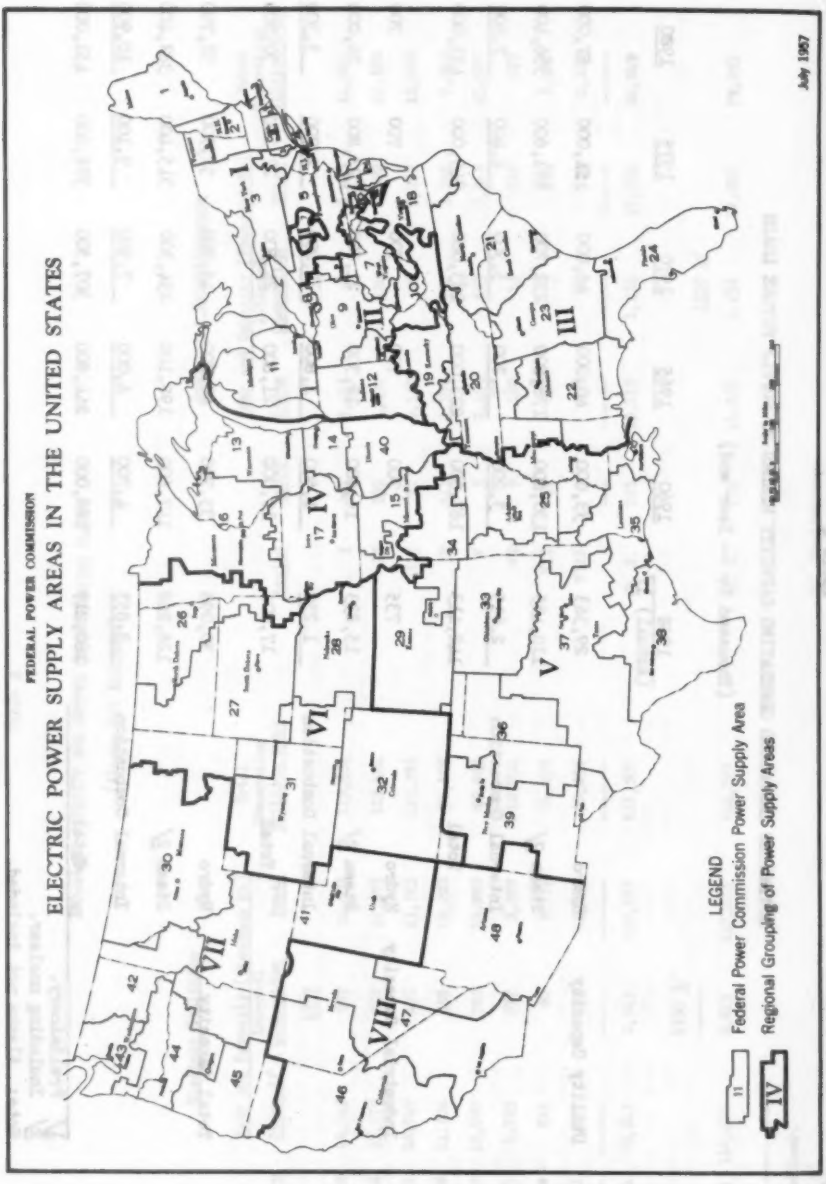
Table 4

ESTIMATED INSTALLED GENERATING CAPACITY NEEDED TO SUPPLY FUTURE LOADS

(Thousand Kw — Year end)

		1958 (Actual) 1/	1960	1965	1970	1975	1980
Utility Capacity	Hydro	29,363	33,000	40,000	45,000	51,000	57,000
	Steam 2/	110,435	130,800	178,800	232,700	291,600	356,400
	Internal Combustion	2,615	3,200	4,200	5,300	6,400	7,600
	Total	142,413	167,000	223,000	283,000	349,000	421,000
Industrial Capacity	Hydro	735	700	700	700	700	700
	Steam 2/	15,833	16,800	19,300	21,600	23,800	26,000
	Internal Combustion	1,238	1,500	1,800	2,200	2,700	3,300
	Total	17,806	19,000	21,800	24,500	27,200	30,000
Total Capacity	Hydro	30,098	33,700	40,700	45,700	51,700	57,700
	Steam 2/	126,268	147,600	198,100	254,300	315,400	382,400
	Internal Combustion	3,853	4,700	6,000	7,500	9,100	10,900
	Total	160,219	186,000	244,800	307,500	376,200	451,000

1/ Preliminary.
2/ Including nuclear.
Note: Alaska not included.


FEDERAL POWER COMMISSION
ELECTRIC POWER SUPPLY AREAS IN THE UNITED STATES
July 1957
LEGEND
Federal Power Commission Power Supply Area
Regional Grouping of Power Supply Areas
I
II
III
IV
V
VI
VII
VIII

LETTER REQUEST TO FEDERAL POWER COMMISSION

Thank you for your prompt reply to our request for a forecast of electric energy requirement in the United States.

On reading the release (#10480) accompanying your letter, we note that this gives us forecasts for the year 1980. In order to have these energy forecasts consistent with our other studies, it would be most helpful if your staff could adjust the 1980 figures to 1975 for us; we are interested only in the total U.S. figures, without regard to the regional breakdown.

* * * * * * *

TRANSMITTAL LETTER FROM FEDERAL POWER COMMISSION

This refers to your letter * * * requesting an adjusted forecast of electric energy requirement in the United States in 1975 and an analysis of hydroelectric power resources in different years of the United States, its allies, and neutral countries, assuming various cost levels and degrees of technological development.

The requested forecast of electric energy requirement in 1975 is shown on the inclosed tabulation. * * *

* * * * * * *

Estimated electric energy requirements of the United States in 1975

Electric energy requirements:	*Million kilowatt-hours*
Utility requirements:	
Farm, excluding irrigation and drainage pumping	39,938
Irrigation and drainage pumping	17,008
Nonfarm—residential	408,775
Commercial	250,620
Industrial	730,315
Street and highway lighting	12,616
Electrified transportation	4,923
Other deliveries to ultimate consumers	36,429
Losses and unaccounted for	167,010
Total	1,667,634
Nonutility generation less deliveries to electric utilities	134,250
Total energy requirements	1,801,884

Source: Federal Power Commission, Bureau of Power, Feb. 26, 1960.

STAFF NOTE.—Energy demand information and forecasts for the OEEC area were obtained by a review of existing literature. An extract from "Toward a New Energy Pattern in Europe," Report of the Energy Advisory Commission (OEEC), (ch. III, pars. 18–48), appears below, and provides pertinent data. See, also, the Euratom document, "Outlook for the Development of Nuclear Energy," appearing in the background information in connection with atomic power.

18. In the last chapter we have traced the important changes in the volume and pattern of energy consumption since 1948. Our purpose in doing so has been to establish as firm a foundation as possible for the forecasts that we have been asked to make of the probable trends during the coming years. But we think we should stress at the outset that the tasks of forecasting are inevitably perilous however much care may be taken, and that projections over as long a period as we have been asked to consider must be subject to very considerable possible margins of error. Nonetheless we recognise that immediate decisions to make long-lived investments in the sinking of coal mines, in the building of hydro-power projects and in the development of nuclear energy require that the best possible attempt shall be made immediately to judge the future pattern of European energy demands. We believe that the dangers of such forecasting are minimised if, as the Council of the O.E.E.C. has proposed, such forecasts are constantly subject to revision and if every effort is made to hold the balance between the inevitable moods of excessive optimism and pessimism which may particularly affect these long projections.

19. We emphasize this because it is for the moment very difficult to predict with confidence the probable future rates of growth of the European economies. During the period 1945-1955 there was a phase of rapid expansion, partly to be explained by the industrial boom stimulated by reconstruction, the overtaking of arrears of replacement, the necessity to develop export capacity as well as by deliberate policies of modernisation and economic development. This phase of rapid expansion was associated with varying degrees of inflation in different countries, and the desire to moderate the inflationary pressures led to measures in various countries which have had the effect of slowing down the rate of expansion. These measures have now been reversed and a further phase first of comparatively rapid re-expansion and then of more moderate growth may be expected to follow. It is difficult at the moment to judge how much lower, if at all, the future average rates of economic growth may be, than those of 1945-1955. It seems

likely that in Europe, as in America, they will continue to be considerably higher than in the pre-war period.

20. We have regarded it as our task to form the most realistic long-term view of the trends of the European economies. The experience of the past two or three years has emphasized that the rates of growth of European economies will not be constant and uniform, and that individual years will exceed or fall short of the trend. The best that can be done, therefore, is to project over various distances of time the probable mean trend and to assume that the excess or deficit of demand in an individual year as compared with the long-term trend will be met by temporary recourse to stock reduction or stock building, to overtime or short-time working, to greater or less imports, and to the various other methods by which flexibility can be achieved. We fully realise that relatively minor changes in the general rate of growth of the economy and of the aggregate demand for energy in all forms may more than proportionately affect the development of certain specific forms of energy and consequently national policies. We shall consider some of the problems involved in later paragraphs of this report.

21. In attempting our forecasts we have for the convenience of all concerned followed the Hartley Commission in treating 1955 as our base year and in making 1975 the final objective. The year 1975 is a useful year of reference since a number of other attempts to project long-term trends, including the Paley Report for the United States, have been made in terms of it. Apart from this, an attempt to look some fifteen to twenty years ahead seems to us to represent what is probably most useful in the general field of energy. But we have not thought it useful to follow the Hartley Commission in studying the year 1960. That is now only one year ahead and is too close for useful planning purposes. We have substituted, therefore, the year 1965.

22. We have followed the Hartley Commission also in their general methods of forecasting demand, but we have not contented ourselves merely with checking their conclusions. We have studied the long-term trends of the European economy *de novo* and, with both more time and more statistical evidence at our disposal, have been able to analyse in rather more detail the current composition of the final consumption of energy and to attempt to build up our forecasts from estimates of future demand in the various main energy-using sectors and of the corresponding aggregate energy demand.

23. The Hartley Commission relied on four means of forecasting:

i) The Secretariat of the O.E.E.C. made a projection of the growth of the gross national products of the area as a whole on certain agreed assumptions and of the corresponding aggregate energy demand.

ii) The Secretariat made a more detailed projection of the growth

in demand for energy in the major industries and in domestic consumption.

iii) Individual members of the Commission made their own forecasts of consumption in their own and neighbouring countries and these were consolidated into a forecast for the whole.

iv) Several of the major oil companies made available their own forecasts of the total energy requirements of Western Europe.

24. The Hartley Commission very reasonably described these estimates as independent estimates. It is perhaps well to emphasize that they are independent in the sense that they represent the independent judgments of different groups of experts on the basis of very much the same body of evidence. The first two methods, being the work of a single body of experts at two different degrees of generality, perhaps represent to less degree complete independence. In relation to the present problem, however, it is not to be expected that wholly independent bodies of evidence are to be obtained. We would agree with the Hartley Commission that the relevant " independence " here is that of different groups with possibly differing preconceptions and differing tendencies to optimism or to pessimism.

25. Our own approach to the problem has been almost identical.

i) We invited the Secretariat of the O.E.E.C. to project again, and with the assistance of more information and more detailed analysis than had been available to them at the time of the earlier enquiry, the gross national product of the O.E.E.C. area as a whole; to estimate the possible end-use composition of the gross national product; and in the light of this to forecast the total demand for energy in the area as a whole in total and for particular sectors of energy consumption and particular types of energy.

ii) We asked our own Working Party to approach the various individual countries, and, in the case of the six countries of the Common Market, the High Authority of the European Coal and Steel Community, and to build up on this basis what we propose to call a " Country-Wise Forecast ".

iii) We again invited the collaboration of a number of major oil companies and they have made available to us their own individual and somewhat differing forecasts of the energy requirements of Western Europe.

26. We have in effect telescoped the first and second methods used by the Hartley Commission. We have not regarded it as necessary to secure agreement between these various estimates. If we had done so the estimates would have ceased to be independent. But where there have been significant differences between the estimates in respect of some individual item we have sought to understand the reasons for

the difference, and in one or two cases small adjustments have been made in the light of further consideration.

27. The differences between the results of the various estimates, as will be seen below, are surprisingly small. It can be regarded as legitimate, therefore, to use some of the more detailed results of one or other of the methods to analyse at a later stage the probable trends in respect of the separate sources or uses of energy.

28. We begin by discussing the probable trend in the demand for primary energy in total and as derived from all the various sources.

Estimate (i). THE SECRETARIAT ESTIMATE

29. This estimate has been prepared for us, as has been said above, by the Economics and Statistics Directorate of the O.E.E.C. Secretariat[1]. We have considered in some detail the evidence that has been presented to us, covering the likely trends of population and the labour force, of employment, of working hours, and of productivity as affected by the probable trends of technology and of capital per head. Over the period 1950-1955 the annual average compound rate of growth of the aggregate gross national product of Member countries combined was 4.7 per cent. Over the period 1955-1975 the effective labour supply, after allowance for some reduction of hours worked, may be expected to increase substantially less than during 1950-1955. On the other hand, the amount of capital per head in industry is likely to increase more rapidly.

30. It has been assumed that Member countries will be reasonably successful in maintaining a high level of activity and a high level of capital investment. The average rates of economic growth that it has been thought proper to assume do, however, make reasonable allowance for an alternation of periods of moderate recession and more rapid advance such as have been experienced during the past ten years; allowance has also been made for the fact that such recessions may be somewhat more severe in the future. We regard these estimates as the best working forecasts that can be made of the most probable trend, and not as representing either an upper or a lower limit of what is possible.

31. On the assumption of a reasonably high level of activity it seems to us right to estimate that the average rate of growth of the total gross national product of the O.E.E.C. area as a whole over the period 1955-1975 will be approximately 3 per cent per annum; the rate may be slightly higher at the beginning of the period and slightly lower at the end. This would imply a growth approximately as follows:

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1. The economic assumptions underlying the Secretariat Estimate are set out in Annex 2.

TABLE 5. SECRETARIAT ESTIMATE OF GROSS NATIONAL PRODUCT IN THE O.E.E.C. AREA

At constant prices.

1955	1965	1975
100	136	183

32. On these assumptions regarding growth of the gross national product estimates have been made of the probable implied demands for energy. The estimates presented are based on what appear to us to be reasonable hypotheses of the forms of expenditure that may be generated by the gross national product and on the volumes of demand for energy in various end-use sectors. Where these demands are for secondary energy—and in particular for electricity or gas—these demands represent demands for the outputs of these secondary sources of energy, and not the demands of these secondary sources for primary sources of energy; the losses in the various processes of conversion of primary energy into secondary energy require to be taken into account before these final demands can be treated as demands for the sources of primary energy.

33. The trends of the final demands for energy by the various end-use sectors are the resultants both of the probable changes in the levels of activity in these sectors and of the probable changes in the use of energy per unit of output. In making these estimates full consideration has been given to both these factors. In a number of individual sectors it seems likely that the more efficient use of fuel will lead to a reduction of its consumption even though the demand for the services provided may be expected to increase.

34. In Table 6 is given the Secretariat's estimate of the probable growth of final energy demand by end-use sectors:

TABLE 6. SECRETARIAT ESTIMATE OF FINAL ENERGY DEMAND BY END-USE SECTORS IN THE O.E.E.C. AREA

	INDICES 1955 = 100			AS PERCENTAGES OF TOTALS OF EACH YEAR		
	1955	1965	1975	1955	1965	1975
Industry:						
Iron and steel	100	150	206	13	15	17
Other	100	130	167	28	29	30
Transport:						
Railways	100	84	58	7	5	3
Other	100	160	228	9	11	13
Domestic and miscellaneous	100	115	133	39	36	33
Ocean bunkers	100	132	181	4	4	4
Total	100	126	157	100	100	100

35. The increases of final energy demand given in Table 6 may be compared with the estimate of the growth of gross national product given in paragraph 31 and with the estimated growth of industrial output:

TABLE 7. SECRETARIAT ESTIMATE OF FINAL ENERGY DEMAND COMPARED WITH ESTIMATES OF GROSS NATIONAL PRODUCT AND INDUSTRIAL PRODUCTION

Indices 1955 = 100.

	1955	1965	1975
Gross national product	100	136	183
Industrial production	100	147	208
Final demand for energy in all sectors	100	126	157
Final demand for energy in industry	100	137	180
Demand for primary energy in all sectors	100	130	172

It will be seen that the estimates imply that the percentage growth of final demand for energy will be about two-thirds as great as the percentage increase of the gross national product. But since an increasing proportion of all energy is expected to be consumed after transformation (with corresponding losses) into secondary energy, the growth of demand for primary energy is likely to be greater than for final demand alone. Thus the estimates imply that the percentage growth of demand for primary energy will be about 87 of the growth of gross national product[1].

36. The Secretariat estimate of the future demand for primary sources of energy to meet these estimates of final end-use demand shown above are presented in Table 8:

TABLE 8. SECRETARIAT ESTIMATE OF TOTAL DEMAND FOR PRIMARY ENERGY IN THE O.E.E.C. AREA

	1955	1965	1975
Million tons of coal equivalent	777	1 010	1 340
Index	100	130	172

1. The ratio of the growth of demand for energy to the growth of the gross national product is affected by many factors including the rate of growth of gross national product itself. A higher rate of growth might imply not only a higher level of capital construction and of activity in industries which are in general heavy users of energy but also a rapid expansion without full exploitation of the possibilities of fuel economy. Conversely, a lower rate of growth might imply a lower ratio. The ratio of 87 per cent that has emerged from our calculations could thus be somewhat affected not only by a different rate of national growth than we have assumed but also by a different pattern of expenditure.

Estimate (ii). THE COUNTRY-WISE ESTIMATE

37. This second estimate, as was said above, represents an attempt to build up on a country-wise basis a set of estimates of final demand for energy both in aggregate and in terms of the various forms of primary and secondary energy. In organising these estimates we have relied on the help of the High Authority for a collective estimate for all the countries included in the European Coal and Steel Community and on estimates for all other O.E.E.C. countries. Naturally, the estimates reflect the economic assumptions made for the different countries. These assumptions are not necessarily identical with those made in the Secretariat's estimate for the O.E.E.C. area as a whole, but we believe that they are broadly consistent. Table 9 shows the results of this method of estimation in a form comparable with Table 6 above.

TABLE 9. COUNTRY-WISE ESTIMATE OF FINAL ENERGY DEMAND BY END-USE SECTORS IN THE O.E.E.C. AREA

	INDICES (1955 = 100)			AS PERCENTAGES OF TOTALS OF EACH YEAR		
	1955	1965	1975	1955	1965	1975
Industry: Iron and steel	100	142	183	12	13	14
Other	100	137	176	29	31	33
Transport: Railways	100	83	70	7	5	3
Other	100	170	225	9	12	13
Domestic and miscellaneous	100	117	127	39	35	32
Ocean bunkers	100	132	181	4	4	5
Total	100	129	155	100	100	100

38. It will be seen that, while the total of the estimated final demand is very close to that reached in the Secretariat estimate, there are differences in some categories. The total estimated increase of industrial demand is little different in the two forecasts, but in the country-wise forecast a rather smaller increase in consumption by the iron and steel industries and a rather larger increase by other industries is envisaged. Some of these differences may, however, be due to slight differences of definition and coverage.

39. In Table 10 the total demands for primary energy reached by this method are given in a form comparable to that of Table 8.

TABLE 10. COUNTRY-WISE ESTIMATE OF TOTAL DEMAND FOR PRIMARY ENERGY

	1955	1965	1975
Million tons of coal equivalent	777	1 040	1 300
Index	100	134	167

Estimate (iii). THE OIL COMPANIES ESTIMATE

40. Four of the major oil companies have assisted us not only by putting at our disposal their individual attempts to forecast the growth of demand in the O.E.E.C. area, but also in explaining to us the basis on which their estimates have been compiled. The estimates are in terms of demand for primary sources of energy and in millions of tons of coal equivalent, and can thus be used, after adjustment to include other forms of energy and ocean bunkers, to check the estimates presented above. It has been thought best to indicate the range of estimates rather than to present the average of the estimates.

41. Table 11 presents, in the same form as was used for the earlier estimates, the estimates of the oil companies:

TABLE 11. OIL COMPANIES' ESTIMATE OF TOTAL DEMAND FOR PRIMARY ENERGY IN THE O.E.E.C. AREA

	1955	1965	1975
Million tons of coal equivalent	777	1 035-1 080	1 330-1 435
Index	100	133-139	171-185

COMPARISON OF THE THREE ESTIMATES

42. The increases of total demand for primary energy resulting from the three methods are compared in Table 12.

TABLE 12. COMPARISON OF THREE ESTIMATES OF TOTAL DEMAND FOR PRIMARY ENERGY IN THE O.E.E.C. AREA

	MILLION TONS OF COAL EQUIVALENT			INDEX		
	1955	1965	1975	1955	1965	1975
Estimate i) (Secretariat estimate)	777	1 010	1 340	100	130	172
Estimate ii) (Country-wise estimate)	777	1 040	1 300	100	134	167
Estimate iii) (Oil companies' estimate)	777	1 035-1 080	1 330-1 435	100	133 - 139	171 - 185

43. It will be seen that the differences between the total demands shown in the Secretariat estimate and in the country-wise estimate amount only to about 3 per cent in each of the years 1965 and 1975, the Secretariat estimate being lower in one case and higher in the other. Such close agreement seems to us to suggest that the probable errors in our forecasts stem from the sort of mistakes of general optimism or pessimism that are likely to affect at a given moment all who attempt such forecasts rather than from errors that may be involved in particular approaches to the problem.

44. The estimates of the oil companies are in general higher than those made either by the Secretariat or by the country-wise method, and the means of the oil companies estimates are 4.7 per cent higher than the Secretariat estimate for 1965 and 3.2 per cent higher for 1975. It seems clear that some at least of the oil companies take a rather more optimistic view of the potential expansion of the European energy market.

THE COMMISSION'S ESTIMATE

45. We have given very careful consideration to these estimates. We have in addition examined the trend of European energy consumption since 1955 and the question whether the forecasts made for 1960 by the Hartley Commission are likely to be fulfilled. In 1956 the growth of total energy consumption was about 2 per cent greater than the higher long-term rate assumed by the Hartley Commission. During the subsequent recession, as has been emphasized above, there has been a temporary halt in the growth of European energy consumption and in 1958 total consumption of primary energy was approximately 4 per cent below the mean long-term estimate of the Hartley Commission and approximately 2 per cent below the lower long-term estimate. It would now seem likely that the European economy may re-expand at a rate comparable to that of the years 1953-1956 after the previous similar halt—a rate considerably higher than normal long-term growth. If that were to happen, by 1960 total energy consumption in the O.E.E.C. area would be close to the lower long-term estimate implied for that year by the Hartley Commission. By 1961 total energy consumption would be up to or above the Hartley Commission's mean forecast for that year.

46. In our view it seems right to assume that, if Western Europe is successful in maintaining over an average of future years a rate of employment not substantially less than has been maintained over the past decade, the demand for primary energy may be expected to increase within the limits set out in Table 13.

47. It would not be impossible to envisage circumstances in which the demand could lie outside these limits. If, on the one hand, there were a failure to maintain a high average level of employment, or if,

TABLE 13. **THE COMMISSION'S ESTIMATE OF TOTAL DEMAND FOR PRIMARY ENERGY IN THE O.E.E.C. AREA**

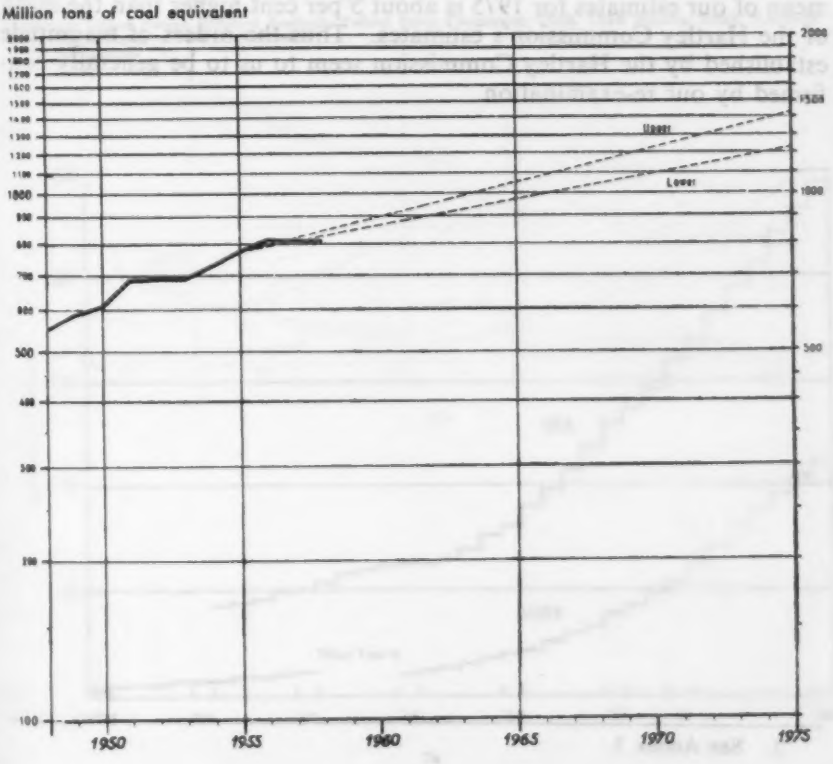
	1955	1965	1975
Million tons of coal equivalent	777	970-1 050	1 225-1 425
Index	100	125-135	158-183

on the other hand, there were an even greater economy in the use of fuel than we have assumed, consumption might conceivably fall below the lower limit. In the unexpected event that low cost energy resulted to a greater extent than we have thought it right to assume in a higher consumption of energy, it is not impossible that it might rise above the higher limit. We believe, nevertheless, that the figures we have given represent the most probable outcome.

COMPARISON WITH ESTIMATES OF HARTLEY COMMISSION

48. Our new estimates lie very close to those made three years ago by the Hartley Commission, when the Hartley Commission's estimates

FORECAST OF TOTAL DEMAND FOR PRIMARY ENERGY IN THE O.E.E.C. AREA



have been adjusted, mainly to cover other forms of energy as well as ocean bunkers and to take account of the actual rather than the estimated consumption of 1955 for which a firm figure was not available when they reported. Table 14 presents the two estimates on a comparable basis[1]:

TABLE 14. COMPARISON WITH HARTLEY COMMISSION'S ESTIMATES

In million tons of coal equivalent.

	1955	1965	1975
Present Commission's estimates:			
Upper		1 050	1 425
Mean	777	1 010	1 325
Lower		970	1 225
Hartley Commission's estimates:			
Upper		1 060	1 360
Mean	777	1 010	1 260
Lower		960	1 160

49. It will be seen that the mean of our new estimates for 1965 is the same as the mean of the Hartley Commission's estimates. The mean of our estimates for 1975 is about 5 per cent higher than the mean of the Hartley Commission's estimates. Thus the orders of magnitude established by the Hartley Commission seem to us to be generally confirmed by our re-examination.

1. See Annex 3.

STAFF NOTE.—Energy demand information for the Soviet Union has been drawn from "A Report on U.S.S.R. Electric Power Developments, 1958–59," prepared by a group of U.S. electric industry executives, on the basis of two visits to the Soviet Union under the auspices of the Edison Electric Institute and the Association of Edison Illuminating Companies. The following extract comprises part 4 of this report.

PART FOUR

FORECASTS THROUGH 1965

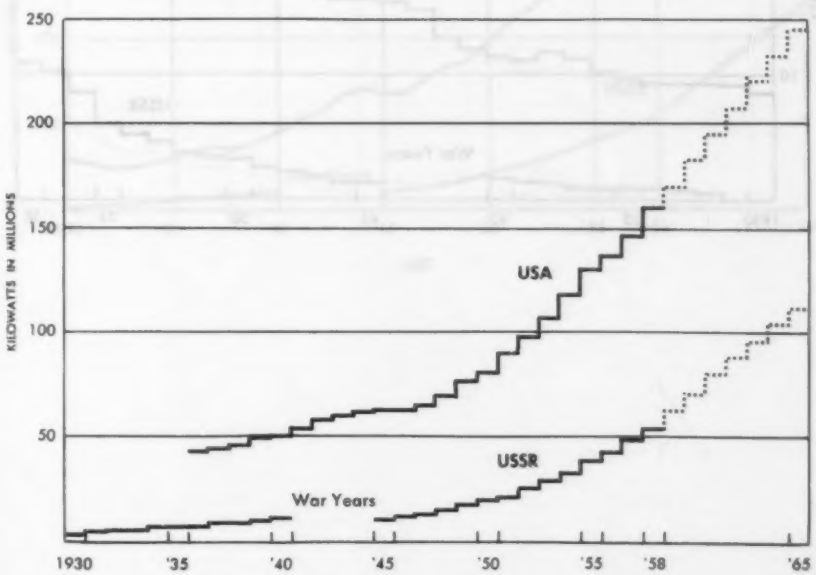
USA AND USSR

TOTAL ELECTRIC POWER CAPACITY: USA AND USSR
Kilowatts in Millions

Year	USA	USSR	Year	USA	USSR
1930	na	2.9	1947	65.1	13.7
1931	na	4.0	1948	69.6	15.2
1932	42.9	4.7	1949	76.6	17.1
1933	na	5.6	1950	82.8	19.6
1934	na	6.3	1951	90.1	22.1
1935	na	6.9	1952	97.3	25.3
1936	43.6	7.5	1953	107.4	28.6
1937	44.4	8.2	1954	118.9	32.8
1938	46.9	8.9	1955	130.9	37.2
1939	49.5	9.8	1956	137.3	43.4
1940	50.9	11.2	1947	146.2	48.4
1941	54.0	na	1958	160.2	53.4
1942	57.2	na			
1943	60.5	na			Forecast
1944	62.1	na			
1945	62.9	11.1	1965 →	245.0	112.0
1946	63.1	12.3			

Sources: United Nations Statistical Yearbook; Federal Power Commission; USSR, *USSR Industry*; USSR, *Narodnoye Khozyaystoo SSSR v 1958 Godu*.

na: Not available.



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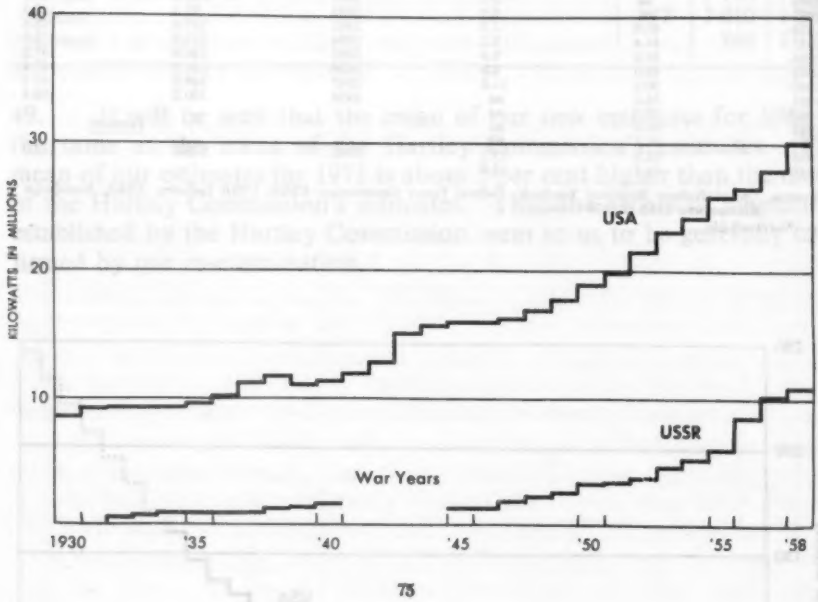
TOTAL HYDROELECTRIC POWER CAPACITY: USA AND USSR
Kilowatts in Millions

Year	USA	USSR	Year	USA	USSR
1930	8.6(1)	0.1	1945	15.9	1.3
1931	9.1(1)	0.1	1946	15.8	1.4
1932	9.3(1)	0.5	1947	16.0	1.9
1933	9.3(1)	0.7	1948	16.6	2.2
1934	9.3(1)	0.8	1949	17.7	2.8
1935	9.4(1)	0.9	1950	18.7	3.2
1936	10.0(1)	1.0	1951	19.9	3.3
1937	11.2	1.0	1952	21.4	3.8
1938	11.7	1.2	1953	23.1	4.5
1939	11.0(1)	1.3	1954	24.2	5.1
1940	11.2(1)	1.6	1955	25.7	6.0
1941	11.8(1)	na	1956	26.4	8.5
1942	12.8(1)	na	1957	27.8	10.0
1943	15.0	na	1958	30.1	10.9
1944	15.7	na			

Sources: United Nations Statistical Yearbook; Federal Power Commission; USSR, *USSR Industry*; USSR, *Narodnoye Khozyaystvo SSSR v 1958 Godu*.

(1) Central station figures only; industrial figures unavailable.
na: Not available.



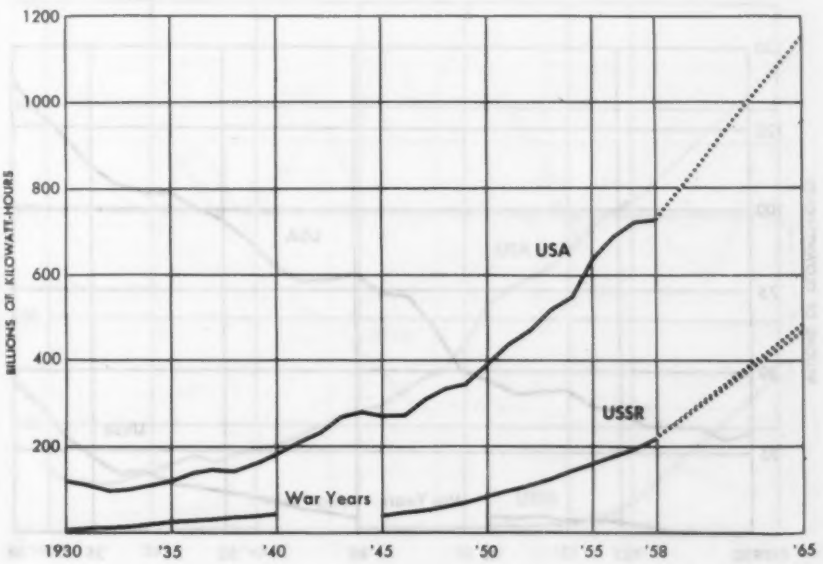
TOTAL ELECTRIC POWER GENERATION: USA AND USSR

Kilowatt-Hours in Billions

Year	USA	USSR	Year	USA	USSR
1928	108.1	4.9	1946	299.6	45.5
1929	116.7	6.0	1947	307.4	58.0
1930	114.6	8.1	1948	336.8	68.3
1931	109.4	10.2	1949	345.1	73.8
1932	99.4	12.8	1950	388.7	88.0
1933	102.7	15.5	1951	433.4	98.0
1934	110.4	19.8	1952	465.1	112.1
1935	118.9	24.8	1953	514.2	126.5
1936	136.0	30.8	1954	544.6	141.4
1937	146.5	34.3	1955	629.0	159.3
1938	142.0	37.4	1956	684.8	179.6
1939	161.3	40.9	1957	716.4	198.7
1940	179.9	45.7	1958	724.0	218.9
1941	206.3	na			
1942	233.1	na		Forecast	
1943	267.5	na			
1944	279.5	na	1965	1 150.0	470.0-480.0
1945	271.3	40.6			

Sources: Edison Electric Institute; Federal Power Commission; U.N. Statistical Yearbook; Harry Schwartz, *Statistical Handbook of USSR*, NICB; USSR, *USSR Industry;* USSR, *Narodnoye Khozyaystvo SSSR v 1958 Godu.*

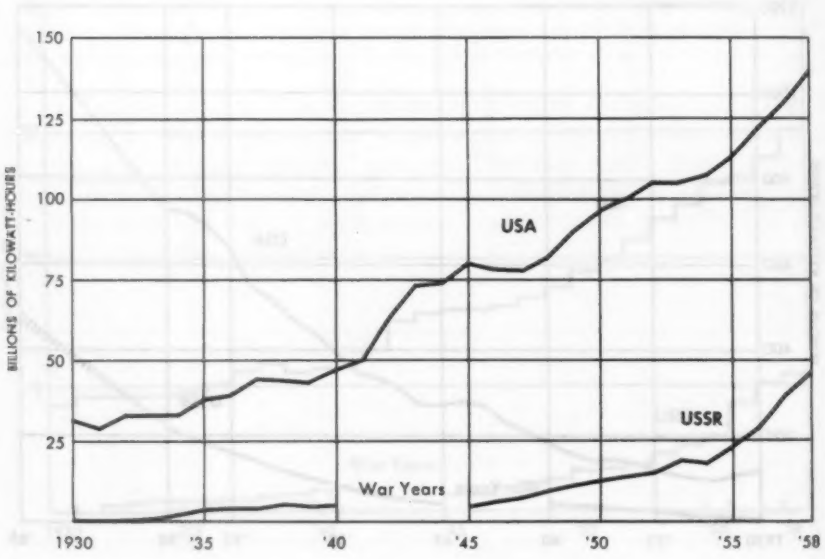
na: Not available.
USA data excludes imports.
USSR data excludes station use.



HYDROELECTRIC POWER GENERATION: USA AND USSR
Kilowatt-Hours in Billions

Year	USA	USSR	Year	USA	USSR
1928	32.9	0.4	1944	73.9	na
1929	32.6	0.5	1945	80.0	4.8
1930	31.2	0.6	1946	78.4	6.0
1931	29.0	0.6	1947	78.4	7.3
1932	32.9	0.8	1948	82.5	9.4
1933	33.5	1.3	1949	89.7	11.5
1934	32.7	2.4	1950	95.9	12.7
1935	36.4	3.7	1951	99.8	13.7
1936	39.1	4.0	1952	105.1	14.9
1937	44.0	4.2	1953	105.2	19.2
1938	44.3	5.0	1954	107.1	18.6
1939	43.6	4.7	1955	113.0	23.2
1940	47.3	5.1	1956	122.0	28.9
1941	50.9	na	1957	130.0	39.4
1942	63.9	na	1958	140.0	46.5
1943	73.6	na			

Sources: Edison Electric Institute; Federal Power Commission; U.N. Statistical Yearbook; Harry Schwartz, *Statistical Handbook of USSR*, NICB; USSR, *USSR Industry*; USSR, *Narodnoye Khozyaystvo SSSR v 1958 Godu*.
na: Not available.



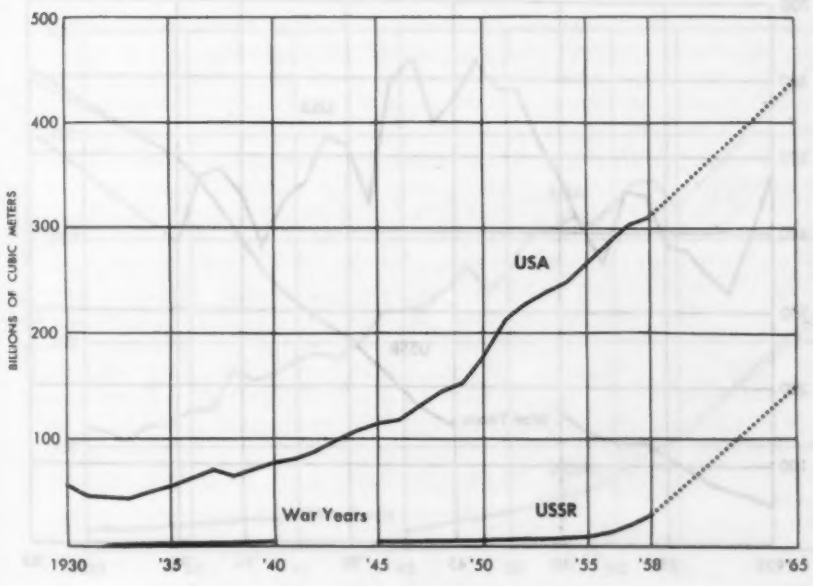
NATURAL GAS PRODUCTION: USA AND USSR
Cubic Meters in Billions

Year	USA	USSR	Year	USA	USSR
1928	45.2	0.5	1946	117.6	na
1929	55.3	na	1947	129.8	na
1930	56.0	na	1948	145.8	na
1931	48.8	na	1949	153.5	na
1932	45.1	1.0	1950	177.9	5.8
1933	45.2	na	1951	211.2	6.2
1934	51.4	na	1952	226.9	6.4
1935	55.8	na	1953	237.8	6.9
1936	63.0	na	1954	247.6	7.5
1937	70.0	2.2	1955	266.3	9.0
1938	66.8	na	1956	285.0	12.1
1939	71.9	na	1957	302.4	19.0
1940	77.4	3.2	1958	311.9	30.0
1941	81.9	na			
1942	89.1	na		Forecast	
1943	99.5	na			
1944	108.0	na	1965	440.0	150.0
1945	114.5	3.3			

Sources: Harry Schwartz, *Statistical Handbook of USSR*, NICB; Joint Economic Committee, "Soviet Economic Growth;" U.S. Bureau of Mines; American Gas Association; United Nations, *Statistical Yearbook—1958*.

na: Not available.

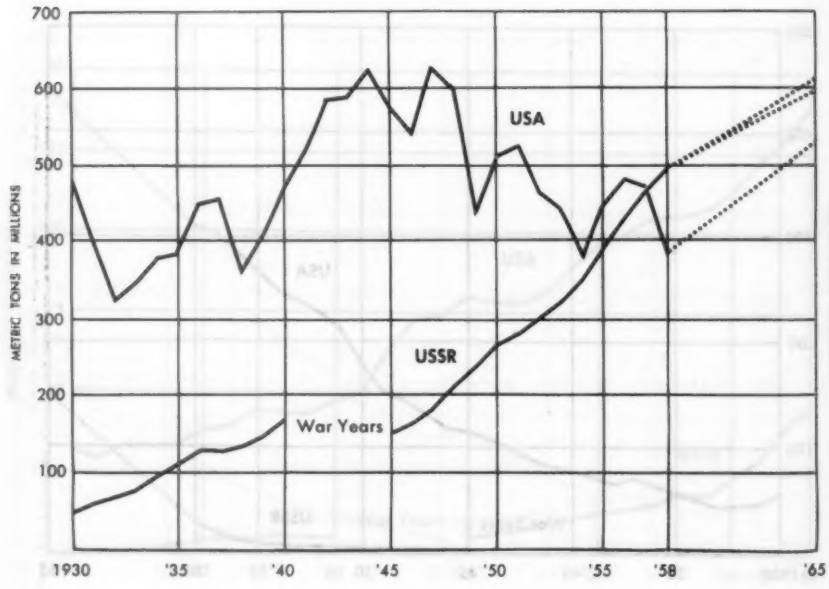
USA data includes both liquid and dry gas figures, minus repressuring, vent and waste. See *Mineral Industry Surveys*, Weekly Coal Report No. 2165, 3/13/59, p. 13 (Bureau of Mines). Data represents marketed production.



COAL AND LIGNITE PRODUCTION: USA AND USSR
Metric Tons in Millions

Year	USA	USSR	Year	USA	USSR
1930	487	48	1947	624	183
1931	401	57	1948	596	208
1932	326	64	1949	436	236
1933	348	76	1950	508	261
1934	378	94	1951	523	282
1935	385	110	1952	460	301
1936	448	127	1953	443	320
1937	451	128	1954	382	347
1938	358	133	1955	445	391
1939	405	146	1956	480	429
1940	465	166	1957	470	463
1941	516	na	1958	387	497
1942	583	na			
1943	590	na		Forecast	
1944	620	na			
1945	574	149	1965	530	596-609
1946	539	164			

Sources: Harry Schwartz, *Statistical Handbook of USSR*, NICB; U.S. Bureau of Mints; National Coal Association; "Targets of Seven-Year Plan for Soviet Economy," *Pravda*, Nov. 14, 1958; United Nations, *Statistical Yearbook—1958*.
na: Not available.



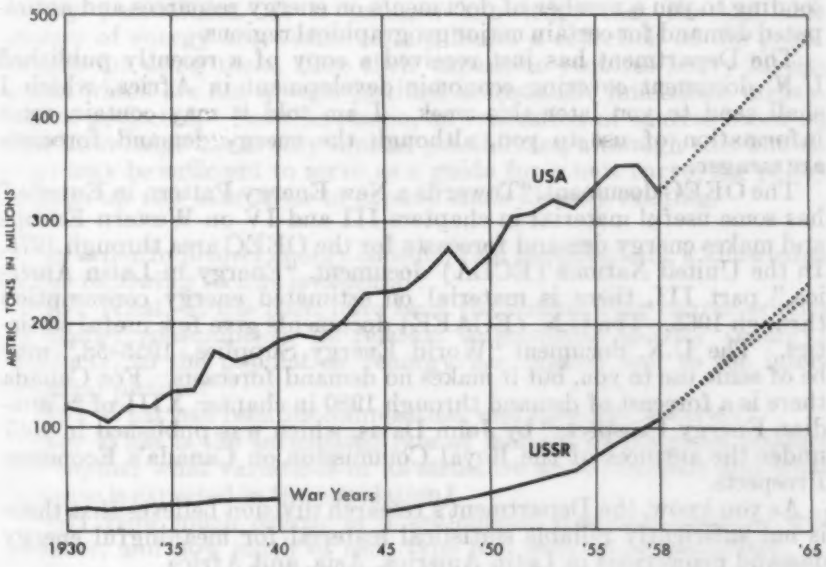
PETROLEUM PRODUCTION: USA AND USSR

Metric Tons in Millions

Year	USA	USSR	Year	USA	USSR
1928	121	12	1946	234	22
1929	136	14	1947	251	26
1930	121	19	1948	273	29
1931	115	22	1949	249	33
1932	106	21	1950	267	38
1933	122	22	1951	304	42
1934	122	24	1952	309	47
1935	134	25	1953	319	53
1936	136	27	1954	318	59
1937	173	29	1955	336	71
1938	164	30	1956	354	84
1939	171	30	1957	354	98
1940	183	31	1958	330	113
1941	189	na			
1942	187	na		Forecast	
1943	203	na			
1944	227	na	1965	479	230-240
1945	232	19			

Sources: Harry Schwartz, *Statistical Handbook of the USSR*, NICB; U.S. Bureau of Mines; American Petroleum Institute; "Targets of Seven-Year Plan for Soviet Economy," *Pravda*, November 11, 1958; United Nations, *Statistical Yearbook—1958*.

na: Not available.



LETTER REQUEST TO DEPARTMENT OF STATE

Re Energy Demand Forecasts for Latin America, Asia, and Africa

* * * it would be very much appreciated if you would request the appropriate agencies of the United Nations to make available their best current estimates of conventional energy resources and their best current forecasts for growth of demand for energy. If possible, this data should be set forth separately by the major geographical economic councils of the United Nations. It is also to be hoped that the forecasts will reflect both prospective population increases and projected growth of gross national product.

* * * * * * *

TRANSMITTAL LETTER FROM DEPARTMENT OF STATE

As we agreed in our telephone conversation the other day, I am sending to you a number of documents on energy resources and anticipated demand for certain major geographical regions.

The Department has just received a copy of a recently published U.N. document covering economic development in Africa, which I shall send to you later this week. I am told it may contain some information of use to you, although the energy demand forecasts are meager.

The OEEC document, "Towards a New Energy Pattern in Europe," has some useful material in chapters III and IV on Western Europe and makes energy demand forecasts for the OEEC area through 1975. In the United Nations (ECLA) document, "Energy in Latin America," part III, there is material on estimated energy consumption through 1965. The U.N. (ECAFE) documents give few useful statistics. The U.N. document "World Energy Supplies, 1955–58," may be of some use to you, but it makes no demand forecasts. For Canada there is a forecast of demand through 1980 in chapter XIII of "Canadian Energy Prospects" by John Davis, which was published in 1957 under the auspices of the Royal Commission on Canada's Economic Prospects.

As you know, the Department's research division believes that there is not sufficiently reliable statistical material for meaningful energy demand projections in Latin America, Asia, and Africa.

* * * * * * *

COMMUNICATION FROM DEPARTMENT OF STATE

Today I received a copy of the United Nations document "Economic Survey of Africa," which I mentioned in my leter of March 15.

I found so little material in it of interest to your study that I decided not to forward it to you.

* * * * * * *

PROJECTION OF ENERGY DEMANDS IN LATIN AMERICA AND ASIA

STAFF NOTE.—The following summary of extracts was prepared for the review by Dr. S. G. Lasky, of the Department of the Interior, and was based upon reports furnished by the Department of State.

LATIN AMERICA

Method used

The Latin America projections are emphasized as being "exclusively for purposes of illustration," which would seem to mean a disclaimer of accuracy and to emphasize that the projections represent order of magnitude only.

"In these projections * * * the limits of interchangeability as between the various sources have been taken into account, as also the fact that there is a relatively independent demand for electricity and for some liquid fuels, etc."

"Once the potential demand is known, the next step is to study supply possibilities. It is common knowledge that the available sources of energy are within certain limits a reflection of the possibilities for using them, since their expansion requires heavy investments which are not always justified unless their immediate utilization is projected. For this reason, an evaluation of sources based on past knowledge offers only limited possibilities, although this knowledge may be sufficient to serve as a guide for a new surveying policy to open up new sources or to expand those already existing."

* * * * * * *

"In order to project energy consumption requirements, a knowledge of the following factors is essential:

"(*a*) What, in the past, have been the outstanding characteristics of energy consumption, its relation to economic activity (energy/product), to the population (energy/*per capita*) and to the international picture?

"(*b*) What has been its composition, and how has it varied?

"(*c*) What is the anticipated rate of increase of the gross product *per capita*; what variations in its structure are envisaged; and what increase is expected in the population?

"(*d*) How much energy is it anticipated that each country will produce, and how much of each type will have to be imported?

"In an analysis of this type, a simplified solution of the problem is often adopted, confined to independent projections of past consumption trends for each type of energy over a given period. This, however, involves certain appreciable risks, and projections made in this way may lead to a substantial over- or under-estimation of future needs. The results obtained from the projection of historical trends will be satisfactory only if future developments conform to these same trends, but they will be erroneous if there is any variation in the rate or characteristics of economic development. It may happen, for instance, that the rate of economic development was very low during the period examined, or that there was a shortage of energy, and a projection developed on such a basis would give very low figures. Conversely, a very rapid increase in energy consumption during the base period might only reflect a gradual easing of an energy shortage, and consequently, once a more normal level of supply was reached, the rate of growth of future requirements might not be so great."

"In this study, it has been deemed preferable to determine future energy requirements by relating them to economic development, rather than by merely exterpolating historical consumption trends for each type of energy."

"Starting with available statistics, the basic method employed has been to make an overall projection of total energy consumption and of total electrical production, relating these to the hypothesis of economic development. * * *"

"The total consumption of energy (net or gross) in a group of countries—including countries with widely varying levels of income and different economic structures—leads to the conclusion that the relationship between total energy consumption and the gross product varies only within very narrow limits. Something similar occurs when the variations in this relationship are examined in one and the same country over a sufficiently long period. It has thus been considered preferable to start in this case with a projection of aggregate energy consumption, based on general projections of the gross product."

"Purely for purposes of illustration, the annual rate of increase of the gross product *per capita* for all the countries was taken to be 2.5 percent (see table 74). * * *"

The following area groupings are made: Group I: Argentina, Brazil, Chile, Columbia, Mexico; Group II: Cuba, Peru, Uruguay, and Venezuela; Group III: Bolivia, Costa Rica, Dominican Republic, Ecuador, El Salvador, Guatemala, Haiti, Honduras, Nicaragua, Panama, Paraguay.

TABLE 74.—*Latin America: Projections of gross product for 1965*

Country	Gross product in 1956 (millions of dollars at 1950 prices)	Annual growth rate of gross per capita product (percent)	Annual rate of growth of population (percent)	Gross product in 1965 (millions of dollars at 1950 prices)
Group I	$34,615	2.5	2.4	$57,718
Group II	8,268	2.5	2.2	13,703
Group III	3,394	2.5	2.4	5,744
Total	46,277	2.5	2.4	77,165

* * * * * * *

"In spite of the fact that * * * aggregate energy consumption figures have chiefly been used, without a detailed analysis of future changes in the consumption structure, it is considered that the results thus obtained—by various procedures, and checked with derived coefficients—are a sufficiently close approximation."

"The lack of detailed figures for the energy consumption of the various economic sectors does not invalidate the corresponding projections of aggregate demand, since this study takes into account, so far as is possible, both possible changes in the structure (especially the greater incidence of industrial activity) and consumption by specific industries. On the other hand, in the more developed countries there is no great difference between the method of sectors and the overall method. The report by a group of experts on the method em-

ployed to forecast the consumption of electric energy shows that both procedures are used in various European countries. The report adds, however, that the method using an average increase appears to be the most popular."

"Furthermore, in addition to the historical trends and characteristics peculiar to each country, the calculations took into account certain factors arising from comparisons with other countries and economic expediency."

* * * * * * *

Projection of net consumption

"Of the various levels at which general balance sheets of energy may be drawn up in order to make projections, net consumption has been chosen in preference to gross, since it is more directly related to economic activity. In practice, the starting point should be energy utilized rather than the net energy consumed, since the difference between the two may be very great, up to the point where an increasing unit consumption in the latter actually means a relative decrease in the unit consumption of energy utilized. Unfortunately, sufficient data are not available to make this calculation, a fault which is not exclusive to Latin America."

"After making the projections of net energy, the next step was the calculation of the corresponding gross energy, an essential step in assessing total production and import requirements and in drawing up the investment and foreign exchange budgets. The conclusions reached regarding the growth requirements of both net and gross energy are not dissimilar, but the need to increase the latter tend to be greater, since, on the one hand, it allows domestic production to contribute more to total supply, and, on the other, since the relative importance of electricity increases—both being cases where energy consumption expands by virtue of its very production."

"In estimating total net energy consumption, its trend per unit of gross product was used."

"It may be concluded that the most probable outcome is that energy consumption per unit of product, which has tended to decline over the long term, will remain approximately constant during the coming years. This, therefore, is the hypothesis adopted for the majority of the countries, with the exception of Argentina and Mexico, where it has been thought wise to allow for a light increase in unit consumption, and of group III, which consists of the least developed countries in Latin America, where a decline of 1 percent annually has been maintained."

* * * * * * *

"According to the method applied, net *per capita* energy consumption will increase at the same rate of 2.5 percent annually established for the gross product, except in Argentina and Mexico, where it will be slightly greater, and in the group III countries, where it will be lower. Thus, a total is reached for 1965 of nearly 108 million tons of petroleum equivalent (as against 63 millions in 1954) and an increase of 30 percent in *per capita* consumption."

TABLE 75.—*Latin America: Projection of new consumption of total energy for 1965*

Country	1954		1965		Net per capita consumption of energy	
	Total net consumption of energy [1]	Consumption of energy per unit of gross product [2]	Net consumption of energy per unit of gross product [2 3]	Total net consumption of energy [1]	1954 [4]	1965 [4]
Group I	45,330	1,310	1,368	78,940	367	496
Group II	12,921	1,560	1,560	21,380	553	726
Group III	4,908	1,446	1,295	7,440	204	233
Total	63,159	1,365	1,397	107,760	369	489

[1] Thousands of tons of petroleum equivalent.
[2] Thousands of tons of petroleum equivalent required to produce $1,000,000 (at 1950 prices) of gross product.
[3] The net consumption or energy per unit of gross product in 1965 was obtained by applying the percentage of annual variation to unit consumption in 1952 which corresponded to the trend curve and to effective consumption in 1952 as shown in the table.
[4] Kilograms of petroleum equivalent.

Projection of gross consumption

"When total net energy consumption, its composition by fuels and electricity and the domestic contribution toward satisfying the demand have been calculated, gross consumption may be estimated."

"Table 77 shows gross consumption of total energy which should be reached in 1965 according to the hypotheses formulated and compares this with the figures for 1954."

"Total gross consumption in Latin America should be 147.5 million tons of petroleum equivalent, or 75 percent higher than in 1954. The different annual rates of expansion of gross consumption in each [group of countries] are due especially to the varying rates of growth of domestic production, since the production and preparation of energy itself requires a greater consumption of energy."

TABLE 77.—*Latin America: Projection of gross consumption of energy in 1965*

	Energy			Total energy per capita [1]	
	1954	1965	Annual rate of increase 1954–65, percent	1954	1965
Group I	61,157	110,790			
Group II	16,690	27,570			
Group III	6,129	9,180			
Latin America	83,976	147,540	5.3	491	669

[1] Kilograms of petroleum equivalent.

ASIA AND THE FAR EAST

The only reference to future demands for energy relate to electrical energy and are contained in the following statements:

"The rate of growth of generating capacity over the past few years has been steadily maintained (see table). In the near future, a considerable number of power projects will be completed; and, according

to the development programs of the countries, by the end of 1963 the aggregate installed capacity of the region as a whole is expected to be in the neighborhood of 35,767 kilowatts. This is a little over twice the capacity of 1955. In other words, the capacity is expected to double itself in an 8-year period. The average increase during 1959–63 should be approximately 10 percent per year."

"Aggregate installed capacity of public supply utilities in ECAFE region

Year	1,000 kilowatts	Percentage increase over preceding year
1955	17,216.1	10.6
1956	18,647.9	8.3
1957	20,362.2	9.0
1958	22,029.0	8.3
1963	35,766.7	[1] 10.0

"[1] Annual average."

"Recent experience has been that the installed capacity in the ECAFE countries has been growing at the rate of about 8 to 10 percent per year. This rate of growth of electric supply installations is expected to be maintained for several years; indeed, this might even be exceeded in the case of some countries."

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